The Application of Precision Forestry Technologies in Logging Operations

by

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Abstract

This study analyzed the use of precision technologies in logging operations, more specifically the use of machine monitoring systems, global positioning system (GPS), and geographic information systems (GIS) to monitor and document logging operations. A mail survey addressed to forest landowners in Alabama assessed their level of knowledge and interest in precision technologies. The objective was to identify potential adopters and approaches to introduce these technologies to landowners and foresters. Survey results showed a low level of GPS/GIS knowledge but a high interest in learning or adopting the technology. The youngest, wealthiest, and best educated landowners were identified as potential adopters. The practical applications of precision technologies in logging were evaluated by using machine productivity and positional data to conduct productivity analysis, to map and document machine activities, and to develop GIS tools to assist harvest planning. Logging crews conducting thinning operations in Alabama were monitored using a machine monitoring system (Multidat) which collected machine operating hours and positional data. Additional information (gross production data, inventory, and maps) was provided by the loggers and landowners. Results indicated that data and analysis of machine monitoring systems can be valuable tools in providing accurate machine information for logging productivity analysis. A major benefit to logging contractors is the availability of the machine performance data to manage people and machines and to plan and budget for operations. A technique that can potentially provide operational maps of the harvested areas was presented for mapping and documentation purposes. Results indicated promising applications for the technique as an accounting tool that logging contractors can use to document activities, as an update to GIS systems highlighting potential issues with stand maps, and as a first map for landowners with little mapping information. The positional, production, and map were modeled in GIS to estimate minimum skidding distances and compare those to actual traveled distances. The result is a wander factor that can be used to more accurately assess skidding productivity. The analytical techniques described show potential to benefit loggers and landowners. Significant technical and analytical challenges remain in implementation of those technologies.

Acknowledgments

I would like to dedicate this work to my son, João Pedro, the most important little person in my life and my greatest inspiration. I would like to thank my committee members, Dr. Mathew Smidt, Dr. Larry Teeter, Dr. Richard Brinker, and Dr. Timothy McDonald for their assistance and direction throughout this study. Dr. Smidt deserves special thanks for all the trust and guidance throughout the research process. I gratefully thank the loggers that agreed to collaborate with this study. I also would like to recognize the support of my family; particularly my wife Lupe for loving and supporting me. Without her love and encouragement this work would not have been possible.

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Chapter 1. Potential for the Use of GPS and GIS Technologies by Forest Landowners in Alabama

Abstract

This study consisted of analyzing a mail survey addressed to forest landowners to discover their use of and their interest in Global Positioning System (GPS) and Geographic Information Systems (GIS). The survey was mailed in 2007 to a sample of over 300 forest landowners in Alabama. The objectives were to evaluate the landowner experience and knowledge of GPS and GIS and to identify the early and the potential adopters of these technologies. Seventy landowners responded to the survey (31% adjusted response rate), but only 59 responses were used for the analyses. Respondents were classified by means of cluster analysis into four types (Multiobjective, Recreationist, Investor, and Indifferent) based on the forest owner's objectives. Survey results indicated that most landowners were not familiar with GPS and GIS (58% and 76%, respectively), but the majority of the respondents (81%) wanted to learn more about these technologies. Most respondents (66%) would agree to pay for a GIS generated map but only at a low cost (less than $200). The investors and the recreationists (youngest, wealthiest, and best educated landowners) were identified as the early and the potential adopters of GPS and GIS technologies, respectively. The success of GPS and GIS adoption depends on advising landowners of their potential benefits. The challenges for bringing GPS and GIS to landowners are related to the complexity and the cost of these technologies. Increasing the access to the GPS and GIS by providing training courses to improve computer skills and technical assistance to early adopters and assistance from professional foresters are possible solutions to overcome these barriers.

Introduction

Precision forestry (PF) is a concept of practicing forestry based on similar principles of precision agriculture. In essence PF relates to the process of implementing management and operational decisions focused the smallest practical unit area (Taylor et al. 2006). Taylor et al. (2006) defined it as "planning and conducting site-specific forest management activities and operations to improve wood product quality and utilization, reduce waste, increase profits, and maintain the quality of the environment". The Precision Forestry Cooperative, at the University of Washington, defined PF as "using high technology sensing and analytical tools to support site-specific economic, environmental, and sustainable decision making for the forestry sector".

Global Positioning System (GPS) and Geographic Information Systems (GIS) are technologies commonly utilized in PF. GPS is a navigational system that calculates a position from at least 24 satellites orbiting the Earth. Data are used to determine the receiver's precise location and to provide a highly accurate time reference almost anywhere on Earth (Kopka and Reinhardt 2006). GIS is defined by the Environmental Systems Research Institute (ESRI) as "a collection of computer hardware, software, and geographic data for capturing, managing, analyzing, and displaying all forms of geographically referenced information" (http://www.esri.com/index.html). Essentially, GIS packages display data collected from the GPS receivers and other sources to provide basic information to help people visualize and understand management decisions. The ability to produce, manipulate, store, and analyze spatial data make GPS and GIS useful tools in the forestry environment.

Examples of GPS and GIS forestry applications developed for research purposes include project planning, traffic mapping, application documentation, elemental time study, and gross production data (Taylor et al. 2001). Project planning with GPS support may improve results and documentation, and may enhance opportunities for multi-shift logging (Reynolds 2000). GPS and GIS have been utilized to develop traffic maps to analyze the extent and severity of harvest disturbance (McMahon et al. 1999, McDonald et al. 2002).

In practice the application of precision technology in forestry faces a primary hurdle in that virtually all the activities in forestry are accomplished by independent contractors. For logging contractors cost pressure is severe because payments for harvesting are the primary or secondary contributor to delivered wood and final product cost. Implementing PF technologies should have benefits to loggers since they have very few options for passing along the costs.

Landowners' acceptance of precision technology may depend on the characteristics of the forest land and on the landowner's objectives for the forest. In general landowner's acceptance of professional assistance and interest in innovations is greater for experienced landowners (Jenkins 2009) and owners of large properties (Doolittle and Straka 1987, Birch et al. 1998). Landowners that are well educated, with higher social status, and with more financial interest in the forest are more willing to try new ideas (Doolittle and Straka 1987).

Successful technology transfer will depend on proving the relevance of PF, evaluating the level of interest from landowners and contractors, and determining the best means to approach the landowners and contractors. The purpose of this study was to evaluate the level of interest and consequently the potential for adoption of precision technologies among the forest landowners in the State of Alabama. Specifically, the survey addressed the following objectives:

- Describe landowners' level of familiarity with GPS and GIS technologies;
- Identify potential adopters of precision technologies which are landowners willing to learn and invest in GPS and GIS technologies; and
- Determine approaches to transfer precision technologies to landowners.

Material and Methods

Mail Survey

A mail survey was developed using the Total Design Method (Dillman 1978) and was sent to over 300 forest landowners in Alabama (Appendix 1). The names of the participants on this survey were randomly selected from a list of nonindustrial private landowners in the State of Alabama (with more than 60,000 names) provided by the School of Forestry and Wildlife Sciences at Auburn University. Questionnaires and business reply envelopes were sent via first class mail. A cover letter explaining the purpose of the study accompanied the questionnaire (Appendix 2).

The questionnaire had questions about the landowner, his or her forest land, his or her experience with computers, and his or her knowledge of GPS and GIS technologies. The survey had a total of 29 questions, 25 closed end and 4 open ended questions. The questionnaire was divided into 4 sections: forest land characteristics and management activities; landowner personal information; property mapping information; and GPS and GIS knowledge and interest in learning or adopting the technologies.

In the survey the forested properties were classified based on acreage and species composition (percentage of pine and hardwoods). Land management activities listed were the existence of a written management plan and the history of forest practices. The property mapping category inquired if the landowner possessed a map of the property and how the map was generated (computer or hand generated). The objective was to assess the quality and source (state forester, landowner, industrial forester, or other) of the mapping information.

The landowner personal information category included questions about the age, level of education, and employment status of the landowner. Landowners were classified into 3 age classes (under 40 years old; 41-60; over 60 years old); 3 education level classes (high school degree or less; some college and college graduate; and graduate degree); and into 3 employment classes (employed; self-employed; and retired).

GPS and GIS knowledge and interest in learning or adopting were assessed with specific questions regarding the use of GPS and GIS technologies. The purpose of these questions was to understand whether landowners were familiar with or had interest in these technologies.

Survey Cluster Analysis

The survey cluster analysis identified the landowner clusters to analyze the differences among types of landowners regarding GPS and GIS usage. Previous studies reported that landowner typology is mostly based on ownership objectives (Boon et al. 2004, Ingemarson et al. 2006). The objective of the cluster analysis was to identify landowner clusters based on ownership objectives, to use the clusters to identify the early and the potential adopters, and to evaluate the best approaches to communicate with landowners regarding GPS and GIS technologies.

Only usable surveys were included in the analyses. Usable surveys were defined as the surveys that had the landownership importance questions answered in its entirety and most of the remaining questions answered. The ownership importance question consisted of grading the objectives for owning forest land on a Likert scale (1 = not important; 5 = very important). Each ownership objective was considered to be a response variable (O1-nature; O2-investment; O3-income; O4-aesthetics; O5-heirs; and O6-recreation). Ownership objective definitions are presented in Table 1.1.

A variable cluster analysis was conducted first in order to identify the relationship among the ownership objectives and reduce the number of response variables. After reducing the number of response variables, a cluster analysis was performed on the scores of the clustered variables. A classification similar to the one applied by Kuuluvainen et al. (1996) was used (see Table 1.2). The cluster analyses were performed using the VARCLUS and the FASTCLUS procedures in SAS Version 9.1.

Results and Discussion

Seventy landowners responded to the survey over a 2 month period. The adjusted rate of response was 31% after discounting the non-delivered surveys. This response rate was comparable with the surveys conducted by Kluender and Walkingstick (2000) and by Greene et al. (2001) (36% and 20% response rates, respectively) but was relatively low when compared to other surveys conducted in the southeast US (Henry and Bliss 1994 with a 75% response rate, Butler and Leatherberry 2004 with a 46% response rate). Of the 70 surveys received only 59 were considered usable for the statistical analyses.

A slightly greater percentage (53%) of respondents owned small properties (< 100 acres) compared to large properties (≥ 100 acres). Results also showed that wildlife improvement was the most common forest practice among all the respondents. The next most frequent practices were planting trees and thinning. About 34% of the respondents did not conduct any forest practices in the past 5 years (Table 1.3).

The majority of the respondents (54%) were 61 years or older, and 37% were already retired. Butler and Leatherberry (2004) reported that forest landowners tend to be older than the national average age with an average age of 60 years. Less educated landowners (high school degree or less) accounted for 32% of the respondents and 25% of the respondents had an advanced degree (graduate degree).

Survey results regarding computer usage and knowledge indicated that a large portion of landowners had access to a computer (83%), but only 46% had intermediate to good computer skills. Internet and e-mail were still unfamiliar to most landowners. Results of landowners' familiarity and level of interest in adopting GPS and GIS technologies showed that 42% knew about GPS, but only 20% knew how to use a GPS receiver. About 24% of the respondents were familiar with GIS software, and fewer had used it before. Most of the property maps (53%) were not computer generated. When asked about their willingness to pay for a GIS generated map, 66% of the landowners would agree to pay for it at a low cost (Figure 1.1).

Survey Cluster Analysis

To identify the relationships among the ownership objectives (Table 1.1) a variable cluster analysis was conducted using the VARCLUS procedure in SAS. The VARCLUS procedure divides a set of numeric variables into disjoint or hierarchical clusters. Associated with each cluster is a linear combination (first principal component) of the variables in the cluster. This procedure maximizes the variance that is explained by the cluster components summed over all the clusters.

Table 1.4 summarizes the results of the VARCLUS procedure. The variables cluster analysis reduced the number of response variables from 6 to 2. These two new variables explained about 68% of the variation. The new response variables were named financial and environmental variables based on the ownership objective variables. The financial variable clustered together the investment, income, and heirs variables. The financial variable related to economic reasons for owning forest land. The environmental variable reflected environmental and recreationist interests for owning forestland and included the other ownership variables (nature, aesthetics, and recreation). The scores of the ownership variables (financial and environmental) were combined to run the analysis for the survey data (combined scores ranged from 3 - not important to 15 - very important).

The FASTCLUS procedure in SAS was used to identify the landowner clusters described on the methodology. FASTCLUS performs clusters analysis in a way that every observation belongs to only one cluster. For this analysis we assigned the 4 clusters defined in the methodology to the FASTCLUS procedure. The summary of the results obtained is presented in Table 1.5. The 4 clusters described in the methodology can be clearly identified by the FASTCLUS procedure results presented in Table 1.5. The top part of the table indicates that the procedure was able to identify the 4 defined clusters and show their respective frequency. Based on the cluster means for the environmental and financial variables scores, it was possible to relate the results of the FASTCLUS procedure with the defined clusters. For example cluster 2 presented high means for both the environmental and the financial variables scores which identified it as the multiobjective cluster. The clusters are graphically presented in Figure 1.2.

The clusters identified in this study share characteristics with the description of landowners clusters from previous studies (Kline et al. 2000, Kluender and Walkingstick 2000, Boon et al. 2004). Cluster 1 had a relatively low score for the environmental variable and a high score for the financial variable and was identified as investor. Cluster 2 had relatively high scores for environmental and financial variables and was identified as multiobjective. Cluster 3 had low scores for both variables and was identified as indifferent. Cluster 4 had relatively high environmental score and moderate financial score. This cluster was identified as recreationist. The recreationist cluster valued timber revenues but valued environment more.

Multiobjective and recreationist clusters together accounted for almost 80% of all respondents. Survey results showed that most of the respondents expressed both environmental and financial interest, but environmental protection was the higher priority.

Survey Analysis

The landowners identified in the indifferent cluster owned small properties and were only 10% of the respondents. The cluster contain the least educated landowners and most were retired (Table 1.6). None of the indifferent respondents had activities on their land in the recent past or have plans for future activities. Indifferent had little financial and environmental interest in their land with low scores for both variables (see Table 1.5). The other 90% of the respondents were mostly well educated (at least some college education) and demonstrated an interest in learning more about GPS and GIS technologies (Table 1.7). These findings agree with the results reported by Doolittle and Straka (1987), who reported that well educated landowners are more willing to try new ideas.

The landowners interested in financial returns (investor and the multiobjective clusters) were the most active in terms of managing forest land. The most common management practices included tree planting, thinning, and road maintenance. Results showed that management practices were also related to property size. Most of the small property landowners reported no forestry practices while most of the large property landowners (almost 60%) conducted 3 or more forestry practices in the past five years. The increase number of practices could simply be related to the increased frequency required with larger acreages.

Survey results for mapping resources showed that the majority of the landowners do have a map of the property and that most of the landowners seek professional assistance to generate the map (Table 1.8). Most maps (53%) were not computer generated. Landowners interested in financial returns had the highest percentage of respondents without a map and/or hand generated maps. This result indicated a disconnection between good descriptions of the land assets and profit expectations.

The level of interest in GPS and GIS was greater for the landowners wanting financial returns from their forest land. Overall the interest level was considerably high, but introducing these technologies to landowners may be a challenge. Survey results indicated a low level of computer knowledge for most landowners and some of the respondents did not own a computer (Table 1.9). GPS and especially GIS require an advanced level of computer skills and some dedication to learning how to use the software and hardware.

Computer skills results suggested that learning computer based technologies such as GPS and GIS may be a challenge. Landowners demonstrated a preference for traditional learning methods (workshops, brochures, video tapes, etc.) instead of using computer (internet/e-mail) means. Haworth et al. (2007) in their study reported that in logging education programs the least common formats are the ones involving computer-based methods and self-learning/independent format. These findings indicate potential obstacles for teaching GPS and GIS to landowners.

Identifying GPS and GIS Adopters

Adopters of new technologies, according to the Diffusion of Innovations theory formulated by Rogers (2003), are classified into 5 categories: innovators; early adopters; early majority; late majority; and laggards. The results obtained by this survey were used to identify the cluster(s) of forest landowners that would fit into the first 2 categories. Early adoption is a function of increasing education and socio-economic status (Rogers

2003), so potential adopters of GPS and GIS technologies were expected to be found in the landowner clusters with high income and high educational level. Early adopters are usually younger in age, have the greatest degree of opinion leadership, and are commonly sought by potential adopters for advice and information about the innovation (Rogers 2003).

Landowner's income was not assessed by the survey questions. The property size, however, was used as an indicator of socio-economic status. Early adopters were then identified as a function of property size, educational level, and age. The landowner cluster that best fit the characteristic of early adopters was the investor. The investor cluster represented about 10% of the respondents, and those landowners were assumed to have the greatest potential for adopting precision technologies. The recreationist cluster contained the youngest of all the landowners and a majority of well educated landowners and was identified as potential adopters. Landowners in the indifferent cluster might be identified as late majority or laggards with regard to new technologies.

Conclusions

The study objective was to improve the understanding of the relationship of forest landowner characteristics to interest in learning and adopting GPS and GIS technologies. Landowners' objectives, forest land history, and level of education and computer skills enabled identification of potential adopters of precision technologies.

The investor and the recreationist clusters were identified as the early and the potential adopters of GPS and GIS technologies, respectively. These clusters represented the youngest, wealthiest, and best educated landowners. Those are all key characteristics of early adopters. Combined these 2 clusters contained 46% of the respondents. Their acceptance of GPS and GIS would have the potential to increase the number properties with GIS generated maps by over 25%.

Survey results also pointed to potential challenges in bringing these technologies to landowners. Challenges for bringing GPS and GIS to the adopters refer to the complexity and cost of these technologies. Obtaining and operating a GPS receiver can be cheap and relatively simple, but purchasing and processing the GPS data in GIS can be expensive, complex, and time consuming. Landowner survey results showed that computer skills on average are not advanced even among the adopters. In such computer-based technologies a low level of computer proficiency is certainly a barrier for their implementation.

Landowners demonstrated a preference in learning these technologies through traditional methods, including workshops, training courses, and professional assistance. Workshops and trainings should address not only the importance and the benefits of applying GPS and GIS technologies but also focus on teaching GIS computer skills and developing GIS tools to simplify the process of generating maps in GIS. Benefits of GPS and GIS application in forestry go beyond a good map, and other applications (e.g. machine monitoring) should also be addressed. Training and technical support should target the early adopters (younger and well educated landowners) but may also be offered to professional foresters. In time forester training may make professional assistance more available to potential adopters.

Although these technologies can bring a number of benefits, the level of interest in learning and adopting GPS and GIS would only be clear with landowners having a better understanding of their benefits. Financially motivated landowners need to understand the importance of having accurate information of forest land assets for better management and better estimation of potential profits. Increasing the access to the GPS and GIS technologies by offering training and technical support to landowners and also to professionals might increase the diffusion of these technologies within the forestry sector.

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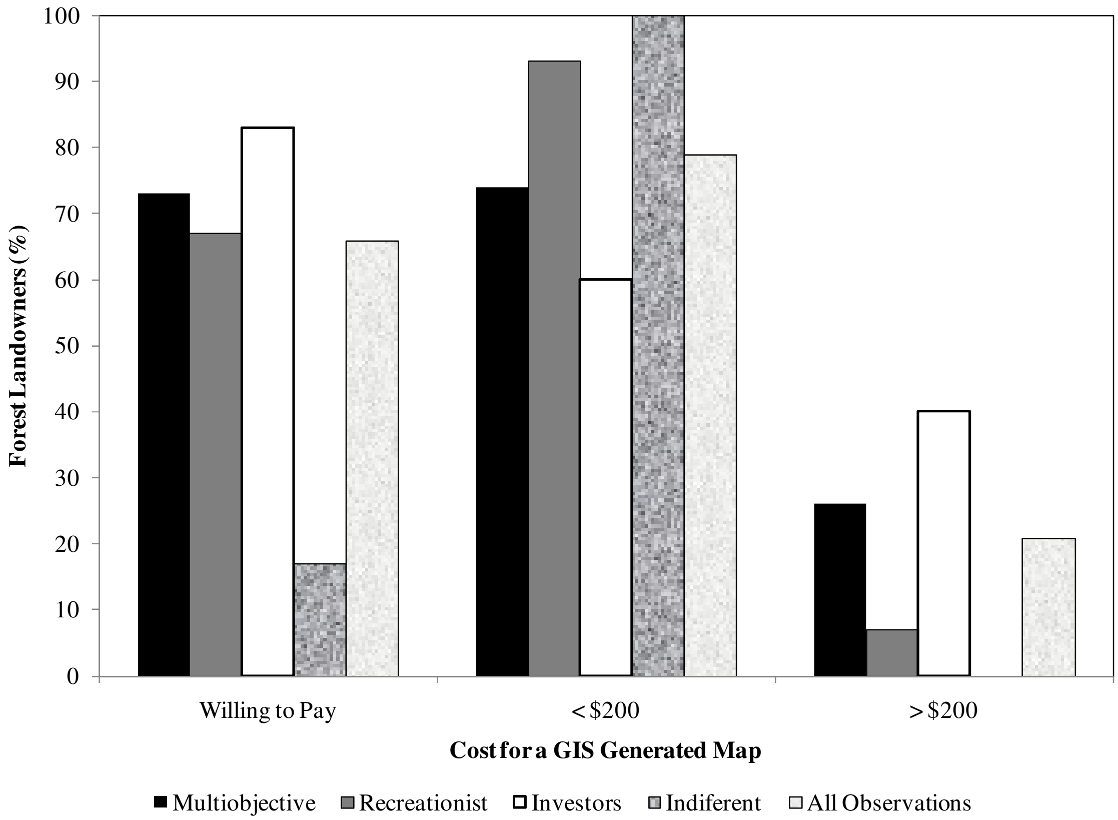

Figure 1.1. — Level of interest and cost range in acquiring a GIS generated map.

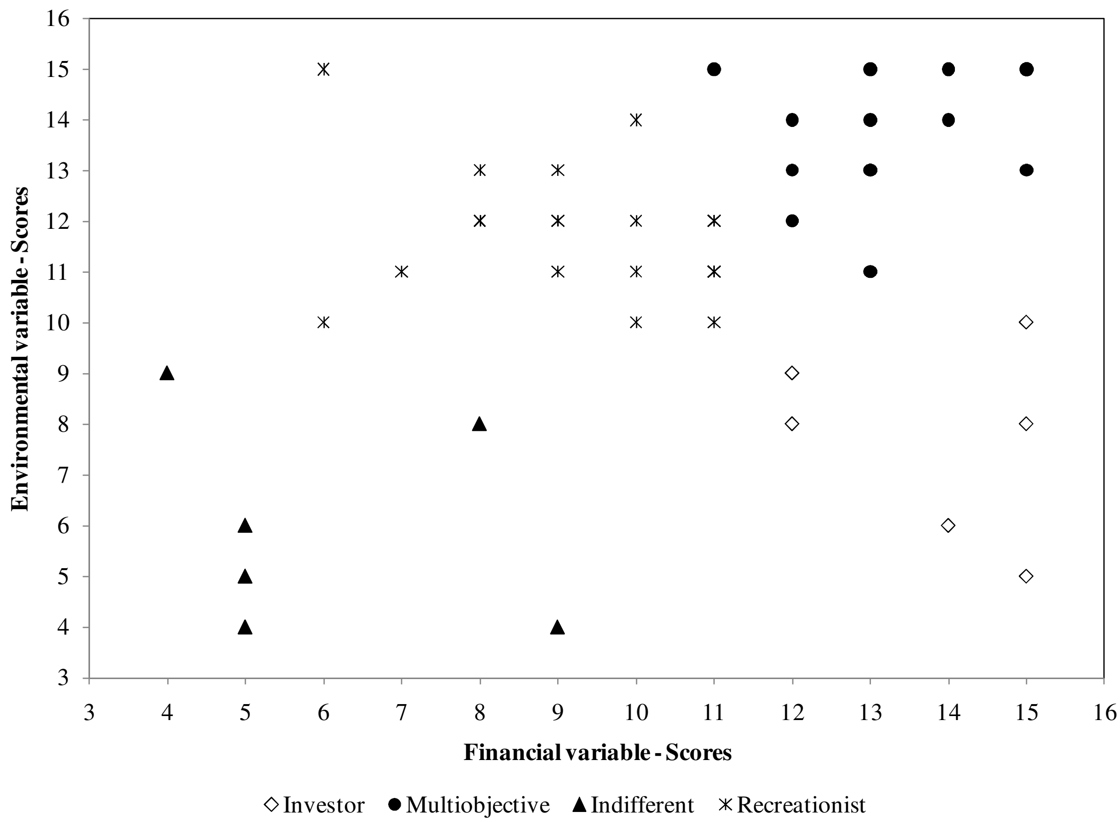

Figure 1.2. — Graphical representation of the landowner clusters: Investor, Multiobjective, Indifferent, and Recreationist.

Table 1.1. ─ Ownership objectives variables.

Variables		Description
O1	Nature	Protection of Nature and Wildlife
O2	Investment	Land Investment
O3	Income	Income (i.e. timber, hunting lease)
O4	Aesthetics	Enjoy beauty and scenery
O5	Heirs	Pass the land to heirs
O6	Recreation	Hunting or fishing

Table 1.2. ─ Pre-defined landowner clusters based on ownership objectives.

Variables	Description
Multiobjective	Landowners giving high scores to both monetary and non-timber values
Recreationist	Landowners emphasizing the non-timber and non-monetary values
Investor	Landowners emphasizing monetary values
Indifferent	Overall lowest scores (both monetary and non-timber values). This cluster was not defined by Kuuluvainen et.al (1996)

Table 1.3. — Forest management practices conducted in the past 5 years.

Mgt Practices	Multiobjective	Recreationist	Investor	Indifferent	Overall
None	12%	48%	17%	100%	**34%**
Planted trees	58%	24%	50%	0%	**39%**
Thin	62%	0%	67%	0%	**34%**
Built/Maintain Roads	46%	5%	50%	0%	**27%**
Prescribed burning	38%	10%	50%	0%	**25%**
Chemical treatments	31%	14%	33%	0%	**22%**
Wildlife improv.	65%	38%	17%	0%	**44%**

Table 1.4. – Summary of variables cluster analysis – VARCLUS Procedure.

R-Squared with 2 Clusters				
Cluster	Variable	Own Cluster	Next Closest	1 - R^2 Ratio
Cluster 1 (Financial)	O2	0.722	0.154	0.328
	O3	0.706	0.063	0.314
	O5	0.528	0.163	0.564
Cluster 2 (Environmental)	O1	0.745	0.071	0.274
	O4	0.824	0.121	0.200
	O6	0.536	0.236	0.608
Total variation explained = 4.060579			**Proportion = 0.6768**	

Table 1.5. ─ Summary of statistical cluster analysis – FASTCLUS Procedure.

Cluster Summary					
Cluster	Frequency	RMS Std Deviation	Max. Distance Seed to Obs.	Nearest Cluster	Distance Between Cluster Centroids
1	**6**	1.678	2.911	4	6.085
2	**26**	1.304	2.807	4	4.590
3	**6**	2.049	3.606	4	6.657
4	**21**	1.470	4.647	2	4.590

Pseudo F Statistic = 61.70

Approximate Expected Overall R^2 = 0.77564

Cluster Means		
Cluster	Environmental	Financial
1	**7.667**	**13.833**
2	**13.769**	**13.462**
3	**6.000**	**6.000**
4	**11.762**	**9.333**

Table 1.6. — Summary of landowner personal information results.

	Multiobjective	Recreationist	Investor	Indifferent	Overall
Landowner Age					
40 and Under	0%	10%	0%	0%	**3%**
41-60	38%	52%	50%	17%	**42%**
Over 60	62%	38%	50%	83%	**54%**
Education Level					
Less/High School Degree	27%	38%	17%	50%	**32%**
Some College or College Graduate	54%	33%	50%	17%	**42%**
Graduate Degree	19%	29%	33%	33%	**25%**
Employment Status					
Employed	23%	45%	50%	0%	**32%**
Self-Employed	27%	20%	33%	17%	**31%**
Retired	50%	35%	17%	83%	**37%**

Table 1.7. — Summary of GPS and GIS knowledge and learning results.

	Multiobjective	Recreationist	Investor	Indifferent	Overall
GPS/GIS					
Know GPS	42%	43%	50%	33%	**42%**
Own a GPS	15%	29%	33%	0%	**20%**
Know GIS	27%	24%	17%	17%	**24%**
Wants to Learn	85%	76%	100%	67%	**81%**
	Multiobjective	Recreationist	Investor	Indifferent	Overall
Learning Method	1-5 Scale (Least Desired=1; Most Desired=5)				
Workshops/ Conferences	3.8	3.9	4.3	3.0	**3.8**
Brochures/books	3.7	4.0	2.7	2.0	**3.5**
Internet/E-mail	3.1	3.5	3.0	1.0	**3.0**
Video tapes	3.8	3.6	3.7	4.0	**3.7**
On-site assistance/Forester	3.7	4.1	3.7	1.0	**3.6**

Table 1.8. — Summary of mapping resources results.

	Multiobjective	Recreationist	Investor	Indifferent	Overall
Property Map					
Have a Map	69%	76%	50%	50%	**67%**
Map Type					
Computer Generated	33%	56%	100%	33%	**47%**
Generated by Hand	67%	44%	0%	67%	**53%**
Map Preparer					
State Forester/Agent	50%	58%	33%	100%	**60%**
Landowner	31%	8%	33%	0%	**18%**
Other	19%	33%	33%	0%	**22%**

Table 1.9. — Summary of computer skills results.

	Multiobjective	Recreationist	Investor	Indifferent	Overall
Computer					
Own	88%	76%	100%	67%	**83%**
Computer Level					
Basic/No	58%	52%	50%	50%	**54%**
Intermediate/ Advanced	42%	48%	50%	50%	**46%**
Internet Use					
Basic/No	62%	57%	50%	50%	**58%**
Intermediate/ Advanced	38%	43%	50%	50%	**42%**
E-mail					
Basic/No	62%	52%	50%	50%	**56%**
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Chapter 2. Using MultiDat Dataloggers for Long Term Productivity Analysis of Thinning Operations in Pine Plantation Stands

Abstract

This study evaluated the use of Multidat dataloggers to continuously monitor logging machines and provide the means to conduct long term productivity analysis of the operations. Multidat dataloggers were installed to collect data from 3 different logging crews conducting thinning operations in Alabama using full-tree systems. A total of 115 shifts of data were collected. Data analysis included graphical analysis of production data, statistical analysis of the machine data, and Geographic Information Systems (GIS) and spreadsheet analysis of Global Positioning System (GPS) data. The GPS data analysis identified the harvest units and calculated daily skidder travel distance. The regression analysis of pooled data for all crews resulted in a model to estimate daily logging production that indicated loader (P-value < 0.0001) and skidder (P-value = 0.0753) as predictors of daily logging production. Differences between logging crews were significant in dummy variable regression of daily shift production. The results indicated that machine data and analysis can be valuable tools in providing accurate machine information for logging productivity analysis. In the long term, logging contractors may generate their own models to estimate shift or weekly production of individual crews. The major benefit of the monitoring system for logging contractors is the estimation of performance of the machines to manage people and machines and to plan and budget for operations.

Introduction

Timber harvesting or logging is the process of cutting, extracting and transporting wood material from the forest to the consumer. Logging is composed of several operations (e.g. felling, loading, unloading, etc.) making it a complex process. Logging operations can have different methods and systems. A logging method refers to the manner the operation is conducted and the form of the product to be extracted (e.g. shortwood or full-tree), and a logging system refers to the sequence of operations conducted (Sundberg and Silversides 1996b) and the set of equipment utilized. The system should always emphasize planning the combination of the operations in order to meet cost and efficiency concerns, instead of considering each operation in isolation (Sundberg and Silversides 1996a). Failure to properly conduct one operation can compromise the subsequent operations in the process.

The ability to accurately measure productivity is essential for planning, managing costs, and improving the economics of logging operations. Productivity is the ratio of the output production per unit of input (Coelli et al. 1998). In logging operations productivity is usually measured as the processing rate (wood volume/worked hours). Continuous monitoring of the operating procedures that directly affect the productivity and costs is advantageous to logging contractors (Davis and Kellogg 2005). Automated monitoring and recording of machine productivity is possible in advanced harvesting machines (e.g. cut-to-length machines), but it is not usually available for full-tree logging systems used commonly in the southern USA (McDonald and Fulton 2005).

Conventional thinning operations in the south consist of full-tree harvesting systems which have high production and relatively low system costs (Brinker et al.

1996). These hot logging operations are interdependent in that earlier operations usually influence the subsequent operation (Sundberg and Silversides 1996a).

Thinning is a silviculture practice to temporarily reduce stand density in order to stimulate the growth of the trees that remain and to increase the total yield of useful material from a stand (Smith et al. 1997). Goals of thinning are to redistribute the growth potential of the stand to the well-formed high quality trees, maintain the growth rate of the stand, and utilize merchantable timber products for financial advantage (Roth 1983). The decision to thin is based on management objectives. Timing and frequency of thinning should consider wood product objectives, site quality, stand density, machine operability, and rotation length (Stokes and Watson 1996).

Logging system productivity in thinning operations can be affected by a number of factors. Granskog and Anderson (1980) reported that system productivity can be affected by stand characteristics such as site index (SI), age, and density. System productivity increases as age and site index increases and decreases as plant density increases (for a given SI and age). Skilled operators, mechanically sound equipment, sufficient wood supply, stand conditions, and harvesting prescription can all affect harvesting productivity (Kluender and Stokes 1996). Adverse weather condition, quota, and moving between stands can also affect system productivity (Greene et al. 2004). Understanding what factors affect productivity is fundamental in optimizing the productivity of the harvesting system. Equipment monitoring systems are suitable for collecting and managing the input (hours) aspect of system productivity.

Investments in monitoring technology include the hardware, software, training, and possibly professional services. Financial benefits may come through information about productivity and machine utilization that result in system changes. Further benefits may be realized by projecting productivity and costs on future harvests. Over the long term, contractors could develop mathematical production models for stand conditions or systems. Contractors could gain a competitive advantage by using the data for harvest planning.

The main objective of this project was to analyze the productivity and machine utilization on pine thinning operations. I anticipated that knowledge and information provided by monitoring would provide financial benefits and competitive advantages to logging contractors that adopt these technologies. The specific objectives were to:

- Evaluate use of the Multidat dataloggers to monitor logging machine operations by analyzing the GPS positional data and the production hours recorded; and
- Generate a regression model to predict daily daily system production using gross production data and evaluate its application to analyze the system productivity of the logging operations.

Material and Methods

Three logging contractors conducting thinning operations in Alabama participated in this study. The study areas (Figure 2.1) were located in Central Alabama (Coosa, Chilton, and Lee counties) and Northwest Alabama (Fayette county). The selection of the logging crews that participated in this study was based on the criteria that they were similar harvest systems and machines conducting similar thinning operations in loblolly pine plantations. Factors such as stand location, topography, stand shape, tree density, and etc., did not affect the inclusion in the study. The participant logging crews were composed of one loader (LD), one feller buncher (FB), and one or two skidders (SK). The monitoring of the logging crews continued for periods varying from two weeks to a few months. A report summarizing the study analysis was provided to the logging contractors as part of the agreement.

The data collection occurred between June of 2007 and November of 2008. Thinning operations were monitored for 115 days (shifts) for 12 different stands and 24 harvest units (harvested area serviced by one logging deck). A summary of the logging crew information and harvesting operations is presented in Table 2.1.

Data Collection and Processing

The Multidat dataloggers were installed in all the machines and powered by the machine electrical system. The Multidat datalogger is a forestry machine monitoring system developed by the Forest Engineering Research Institute of Canada (FERIC) to help loggers and forest managers obtaining information on machine activity. Previous studies have evaluated the use of the Multidat datalogger as an alternative to monitor machines of full-tree logging operations (Brown et al. 2002, Davis and Kellogg 2005). The Multidat datalogger can be GPS enabled to track machine position (Brown et al. 2002).

The dataloggers collected machine working hours and location (GPS positional data). Parameters were set on the dataloggers by creating a configuration file with the specifications of each machine and by determining the threshold setting of the internal motion sensor. The internal motion sensor in the Multidats is set to detect movement of the machine not vibrations of the engine. The threshold point for the Multidat motion sensor was set to 7 for all the machines (Multidat Documentation). Vibrations above the threshold point determined the true machine operating time. Short or incidental stops (less than 1 minute in duration) were ignored.

An external antenna was attached to the GPS enabled dataloggers and placed in a location to capture satellite signals. The GPS in the feller bunchers recorded a position at 30 seconds intervals, and in the skidders it recorded a position based on a pre-determined distance interval of 4 meters. This approach was used for the skidders in an attempt to calculate total distance traveled by the skidder by summing the number of positional points.

Data were downloaded periodically from the logging machines using a personal digital assistant (PDA). The data were transferred from the PDA to a computer and processed using the Multidat software. The Multidat software generated a graphical analysis of the data to identify missing information, produced weekly reports of machine hours, and exported positional data in a point shapefile format for analysis using ArcGIS 9 - ArcMap Version 9.2.

Positional Data Analysis

Use of GPS positional data in this study was confined to the identification of the harvest units and calculation of daily skidder travel distance. The skidder and feller buncher shapefiles were viewed and analyzed in ArcMap. I used the machine shapefiles to identify, delineate, and generate a map of all the harvest units and used the harvest unit shapefiles to determine date and time of harvesting operations. By knowing the exact dates and time of operations in a harvest unit I could relate the machine positional data to the gross production and productivity data and was able to calculate these parameters for each harvest unit.

The daily skidder travel distance was calculated by summing the distances between the points collected. To calculate the distances between points, positional data were converted from latitude and longitude coordinates to Universal Transverse Mercator (UTM) coordinates (X and Y). After conversion the distance in meters between points was calculated using Euclidean geometry.

Productivity Data Analysis

Production data were available from the logging contractor as information about each truck load delivered (load weight, specie, wood product, destination, and delivery date and time) and normal shift hours or scheduled machine hours (SMH). The observations for the analyses were generated for each machine for each day. Measures generated from the raw data included the machine utilization rate (productive machine hours divided by schedule machine hours - PMH/SMH), machine productivities (tonnes/PMH), and logging crew production (tonnes/day).

A case study analysis on Logger 3 (Table 2.1) is presented to evaluate the value of the data collected over long periods. The analysis included the evaluation of machine and system performance over the data collection period.

Since harvests and systems were similar, all the data were pooled for a regression analysis of daily production (tonnes). The explanatory variables for the analysis are defined in Table 2.2. The stepwise selection technique available in the SAS software was used to identify the significant explanatory variables, at the stepwise default level of significance $\alpha = 0.15$.

Statistical tests were applied to test the effects of stand and logging crew differences on logging production. Dummy variables for logging crew were included in the full regression model (Table 2.3). The Tukey HSD (Honestly Significant Differences) test was applied to determine differences between loggers and between stands ($\alpha = 0.10$).

Results and Discussion

Data were lost through the study period from power source issues and satellite reception. Power source issues included blown fuses or disconnected wires. In these situations data losses could have been avoided or minimized if the interval between data downloads were shorter. Data were usually downloaded every 3-4 weeks. GPS data loss occurred from either poor satellite reception or problems with the external antenna. Poor satellite reception may have resulted from factors such as satellite orbit position or canopy cover effect.

The harvest unit parameters and a summary of the productivity data analysis parameters are presented in Tables 2.4 and 2.5. Logging production, machine PMH, and machine utilization rate (UR) parameters presented in the tables are daily averages for the harvest units. Parameters in Table 2.4 show the range of harvest unit sizes and volume removal rates (tonnes/ha). Harvest unit parameters ranged from 3 to 25 hectares in size and from 15 tonnes/ha to 159 tonnes/ha in removal rates. Machine UR was higher for Logger 1 and pooled UR was around 50% (47, 50, and 53% for the feller buncher, loader, and skidders, respectively) for all machines.

Case Study Analysis

Logger 3 was monitored for 38 days of operation. During that time the crew harvested approximately 71 hectares in 6 harvest units. Crew production ranged from 125 to 146 tonnes/day and averaged 141 tonnes/day. Machine UR ranged from as low as 30% to as high as 64% with averages of 40, 47, and 48% for the feller buncher, the loader, and the skidder, respectively. Skidder travel distances ranged from 20 to 34 km/day and averaged 26.6 km/day (Tables 2.4 and 2.5).

The daily machine utilization rate, productivity, and performance were compared to maximum productivity for each machine (Figures 2.2, 2.3, and 2.4). Maximum production rates were 66.2, 49.1, and 54.6 (tonnes/PMH) for the feller buncher, the loader, and the skidder, respectively. On average machines performed within 50-60% of the maximum productivity. For most days the loader had the lowest production rate. Loader production could represent either loader production or could reflect external production limits (quota or trucking capacity).

Skidder productivity and UR were related to skidder travel distance. This effect can be noticed between days 28 and 34. In this period the skidder travel distance was high (harvest unit 23 – Table 2.4) and skidder UR was also high (Figure 2.2), but skidder productivity and performance were at the lowest levels (Figures 2.3 and 2.4). Another factor affecting productivity and machine utilization was shortage of operators during operations. Days with high production rate and low UR indicate crew operation with only 2 operators on 3 machines (e. g. days 4 and 8). Changing logging decks did not seem to impact operations (days 10, 14, 21, and 35) since no particular pattern in machine parameters was identified for these dates.

The analysis of the case study results indicated that data from the machine monitoring system can provide valuable information to assist logging contractors in understanding the fluctuations in machine performance and logging productivity. The most important information to logging contractors may be the accurate measure of productive machine hours. Tracking machine hours can be an especially valuable tool to contractors who do not work with the crew daily.

Logging Production Model

Results of the regression analysis included the selection of the model that best estimated the daily logging crew production. The correlation matrix of logging production and the explanatory variables included in the full model is presented in Table 2.6. Results indicated strong correlations between most variables and daily production, and among the explanatory variables except for variable NMach (number of machines). Figures 2.5, 2.6, 2.7, and 2.8 showed a linear relationship between daily logging production and machine explanatory variables. In all cases production increased as variable values increased.

The stepwise selection in SAS ($\alpha = 0.15$) selected the following reduced model as the best predictor of daily logging production:

$$Production = 21.2596 + 21.6926*LD + 0.5998*SkDist$$

Where:

Production = daily production (metric tonnes);

LD = loader productive machine hours (PMH per day);

SkDist = total skidder travel distance (Km/day).

The stepwise selection resulted in a significant model (Table 2.7). The parameter estimates for the intercept, LD, and SkDist had t-values that were all significant at P = 0.10. Model assumptions for normality, linearity, and constant variance were met for the selected model. The presence of outliers in the selected model was verified by the studentized residual plots of shift production versus the predicted values (a total of 8 outliers). The outlier observations were checked for errors and their removal was not justifiable since they represented empirical data. The model explained about 74% of the variation of daily production and indicated the loader and the skidder as predictors of daily logging crew production. System production increased as loader PMH and/or skidder travel distance increased. The 90% confidence limits for the parameter estimates (Table 2.7) is an indication of the model weakness in accurately estimating daily production.

The Tukey HSD statistical test applied to analyze the effects of loggers and stand differences on the estimation of daily logging production resulted in no statistical differences for stand effect, but pointed to differences between loggers. Results of the Tukey test indicated a significant ($\alpha = 0.10$) difference between logger 1 and 3. The stepwise selection on the full model (including the dummy variables from Table 2.3) resulted in the following model for daily logging production (tonnes):

$$\text{Production} = -16.202 + 27.510*LD + 4.669*FBL2 - 10.157*FBL3 + 11.320*LDL3 - 10.873*SkTotL3 + 6.782*NmachL2 + 19.597*Nmach3$$

The ANOVA table and the parameter estimates for the selected model are presented in Table 2.8. The model included all the variables for Logger 3, indicating a significant difference between Logger 3 and Logger 1. Some differences between

Loggers 1 and 2 were also indicated in the model (FB and Nmach). These results show that logging crew differences had an impact in estimating daily production and the extent of this impact should be considered if generating a production model for multiple logging crews.

Conclusions

This study intended to evaluate the benefits of monitoring logging systems. The results indicated that data and analysis can be a valuable tool in providing accurate machine information for logging productivity analysis. Data and analysis can provide logging contractors the information to accurately assess their system productivity and to identify issues that affect system productivity. For example accurate measure of machine worked hours can assist logging contractors in controlling operators' work reports, which can have a direct impact on harvesting costs in a system where operators are typically paid by the hour. System improvement may also come from the identification, analysis, and improvement of system's bottlenecks.

In the long term the logging monitoring system can provide data for logging contractors to generate production models for their individual crews. These models could incorporate stand variability (data collected from numerous stands harvested over time) and eliminate crew differences which may result in better estimations of logging production. Individual models could be used for harvesting planning to optimize system productivity and reduce costs. For example a good estimation of system production may help harvest planners to better plan trucking supply. Harvest planners may also use the model to estimate stand harvesting time which can be used in harvesting plan preparation.

Long term plans can help contractors to plan for the logistics of the operations and to secure the next harvestings ahead of time. Results of this study showed that the Multidat is a reliable alternative for monitoring logging operations. Its ability to accurately collect information on machine productivity and positional data can provide logging contractors reliable data for the system analysis.

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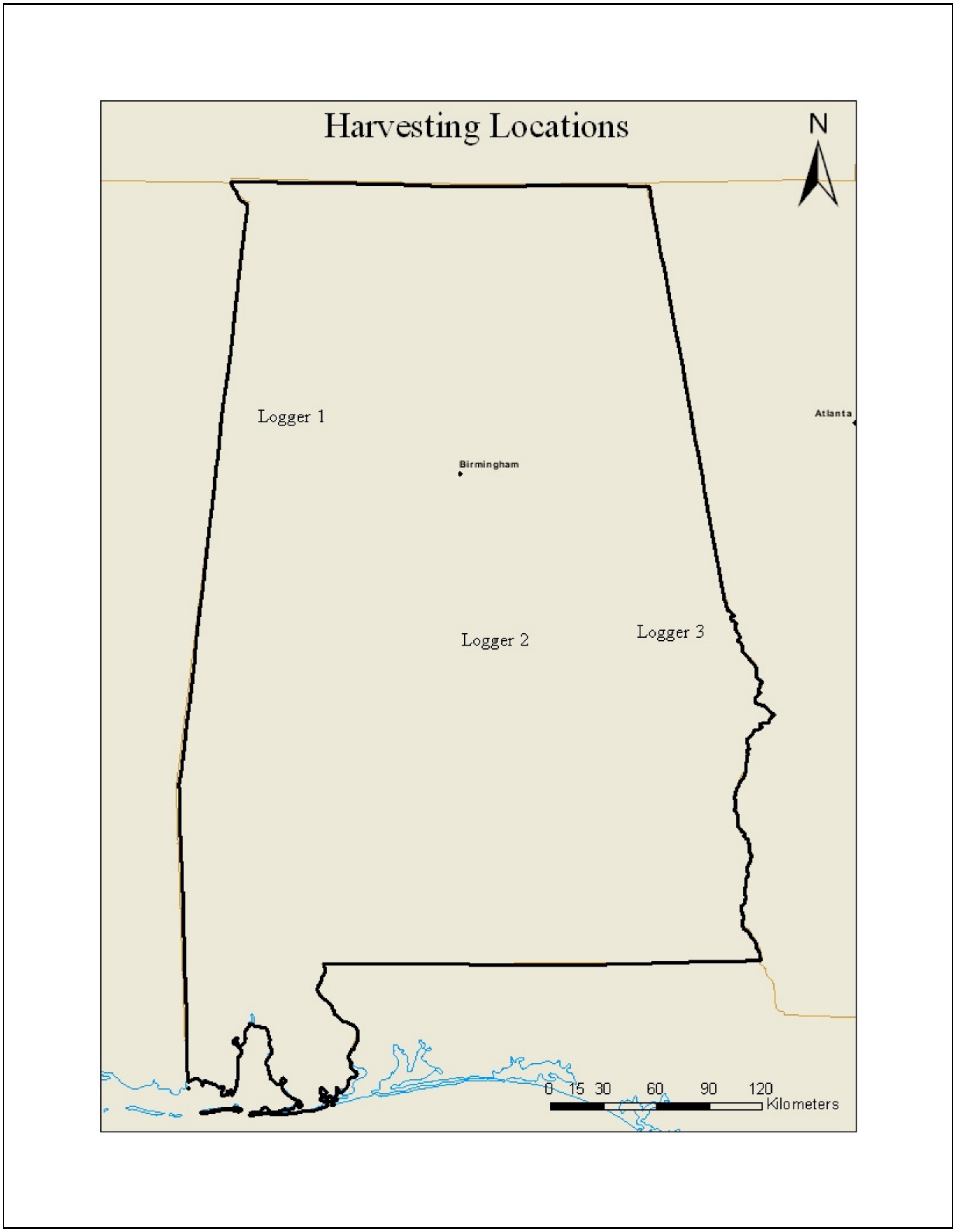

Figure 2.1. – Geographic location of the harvested areas.

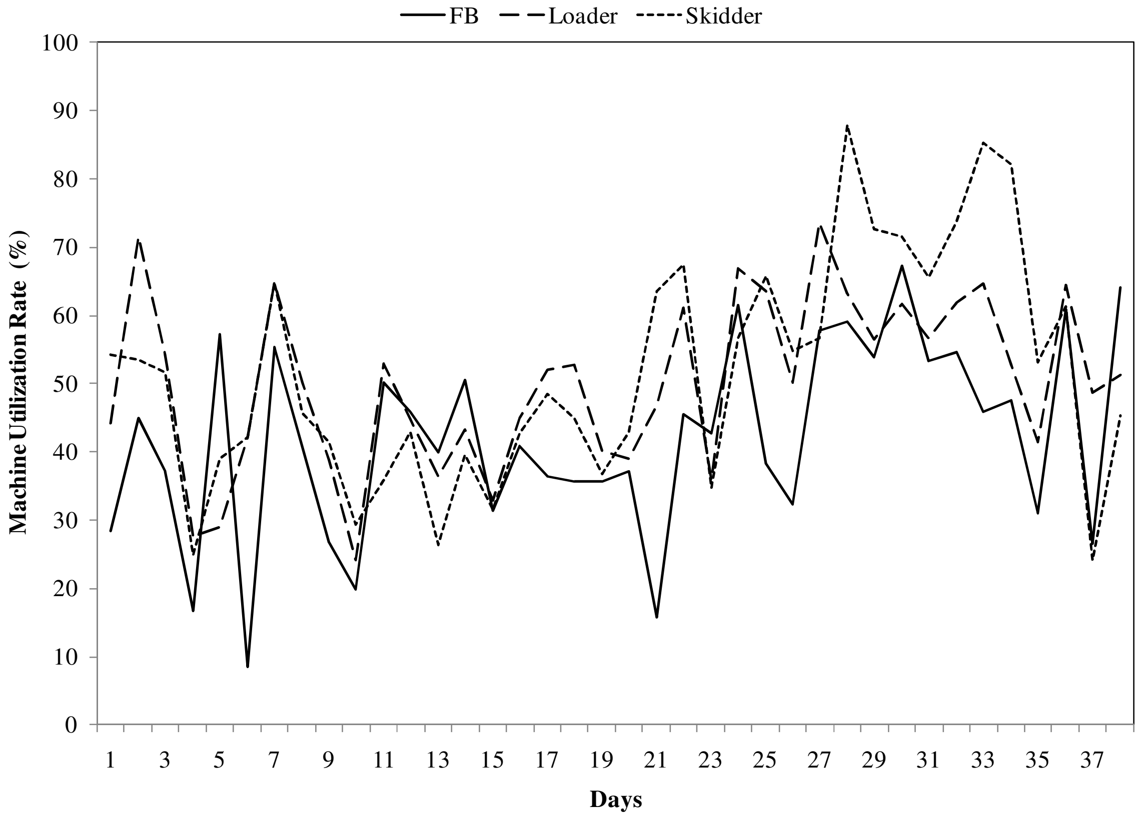

Figure 2.2. – Daily machine utilization rate – Logger 3.

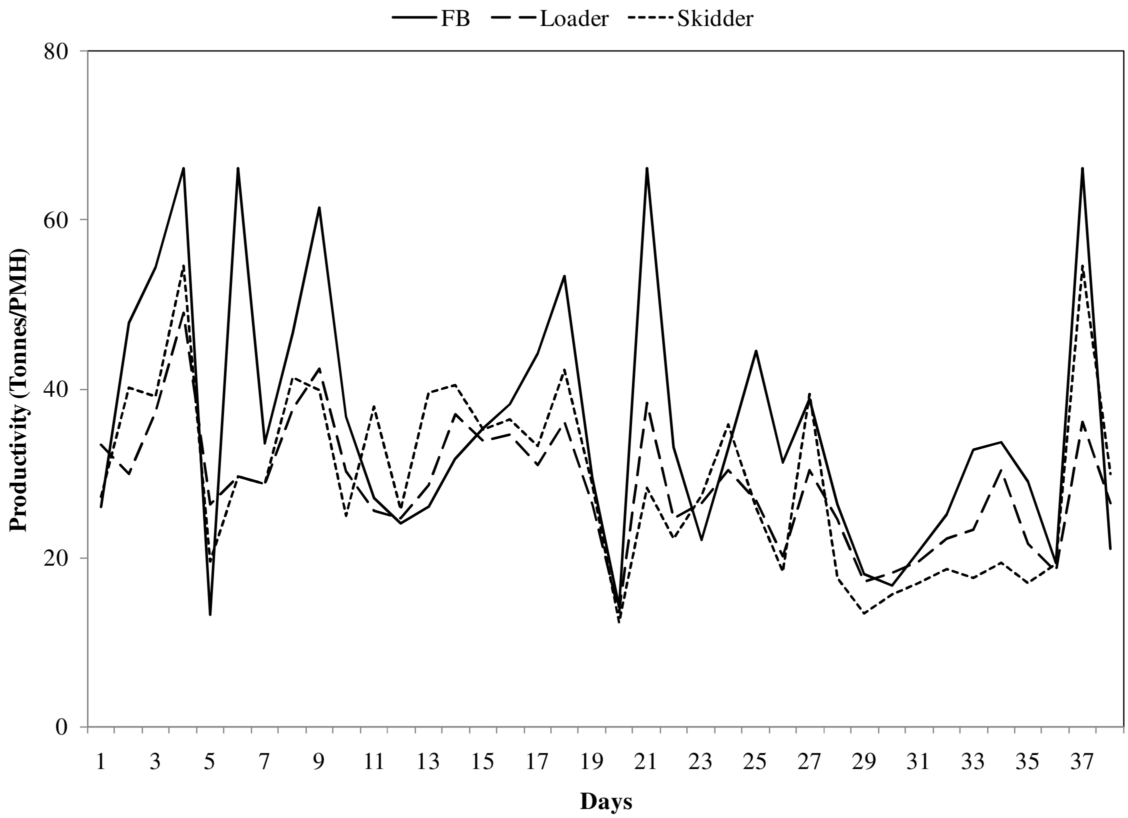

Figure 2.3. – Daily machine productivity – Logger 3.

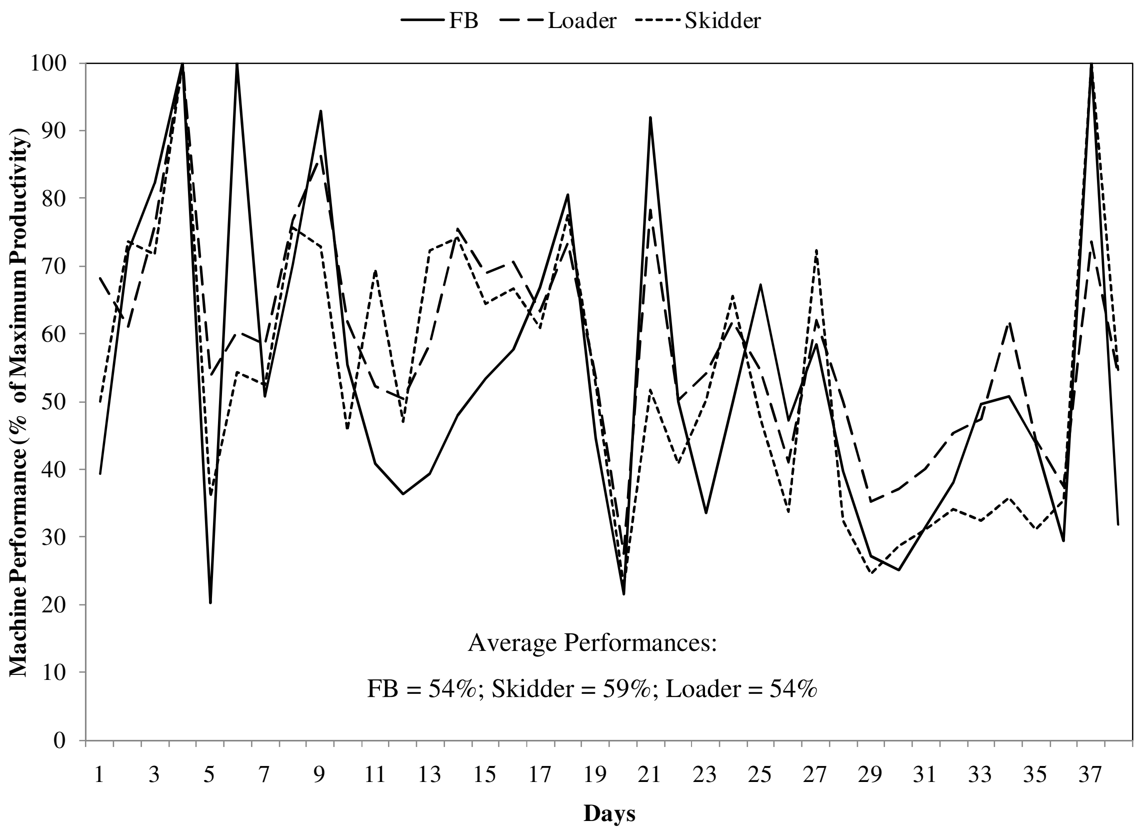

Figure 2.4. – Daily machine performance compared to maximum productivity - Logger 3.

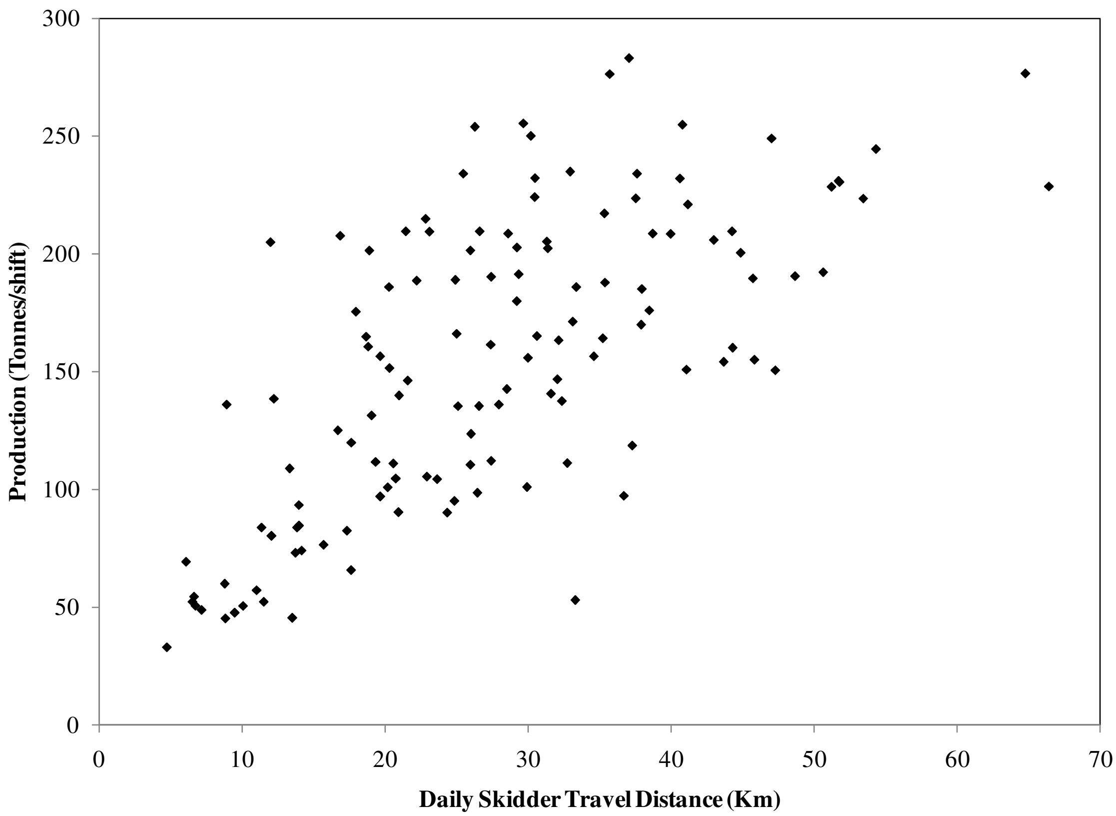

Figure 2.5. – Scatter plot between daily production vs. daily skidder travel distance.

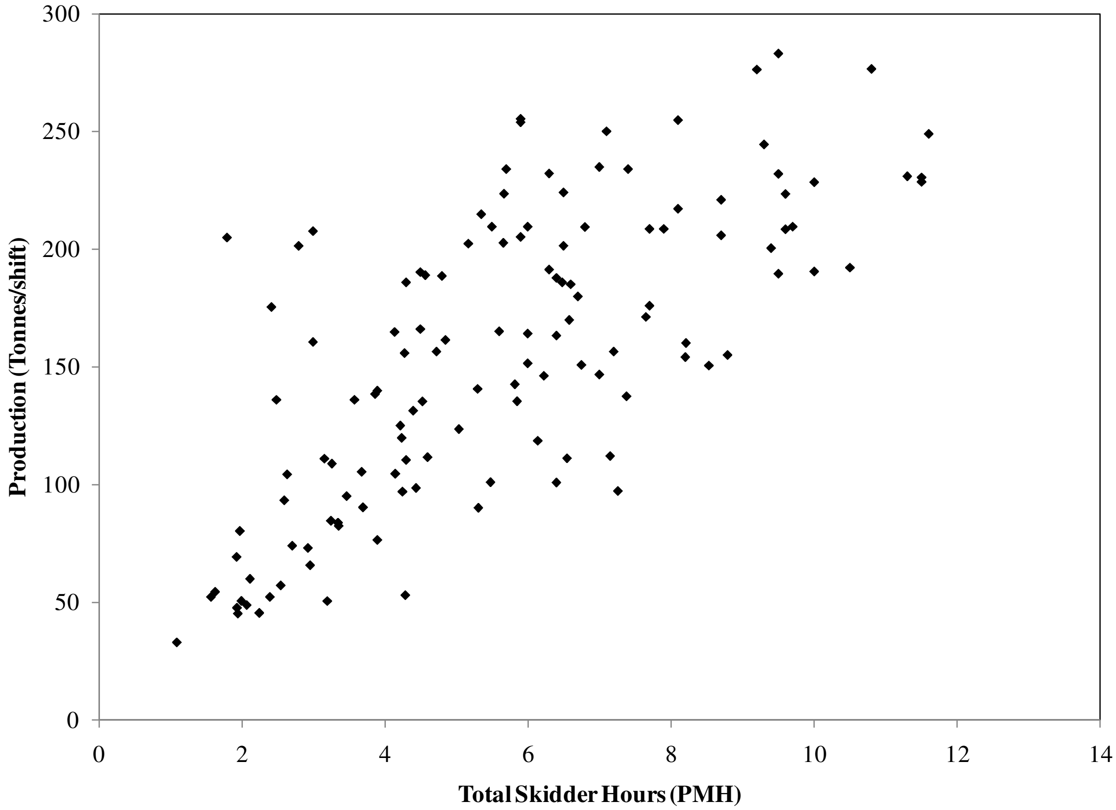

Figure 2.6. – Scatter plot between daily production vs. total skidder productive machine hours.

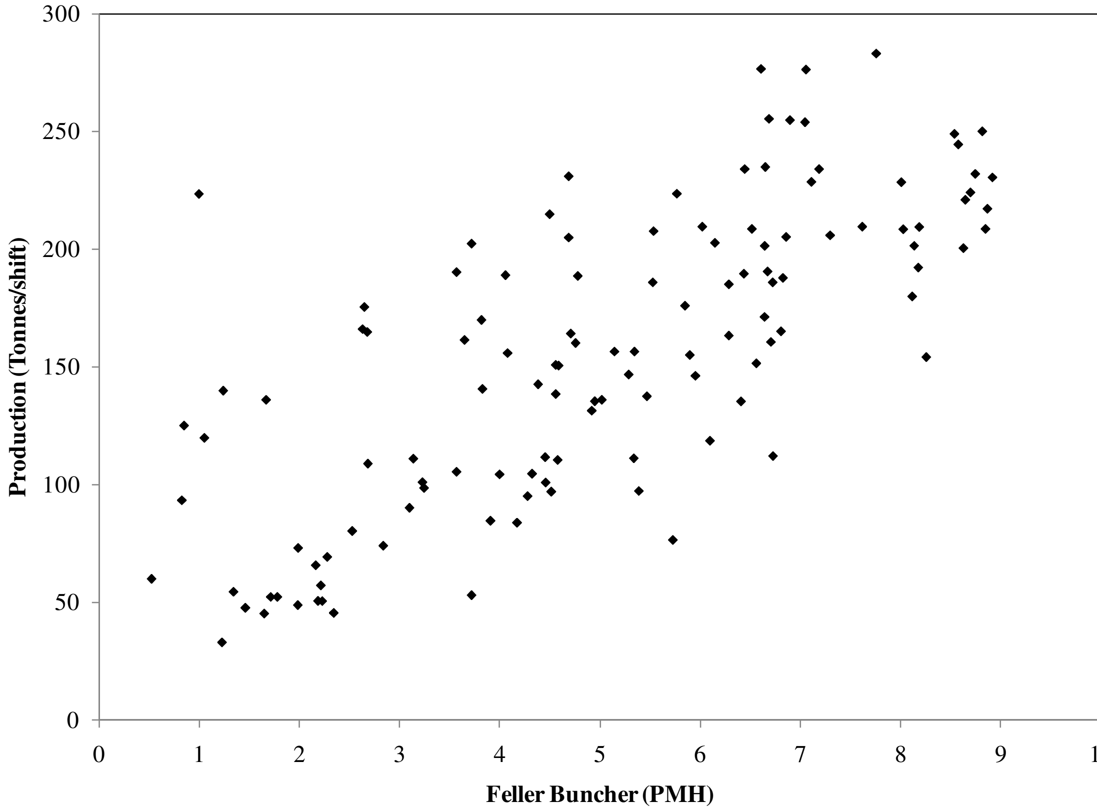

Figure 2.7. – Scatter plot between daily production vs. feller buncher productive machine hours.

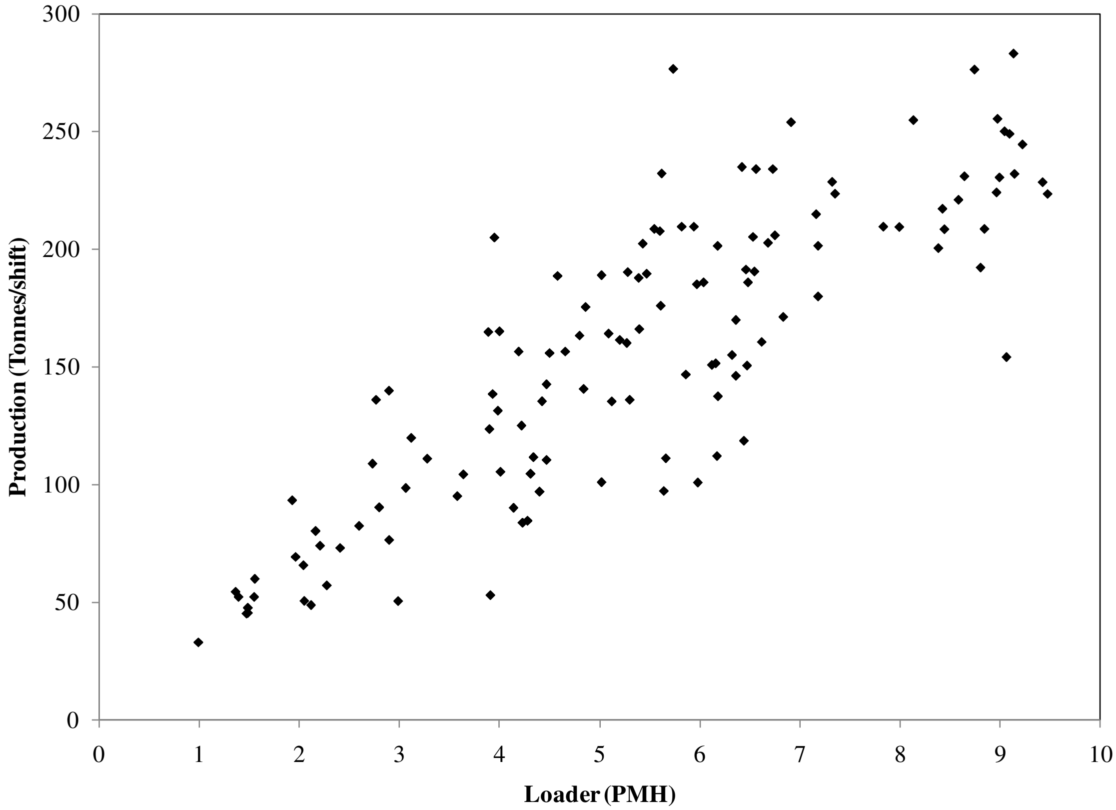

Figure 2.8. – Scatter plot between daily production vs. loader productive machine hours.

Table 2.1. – Summary of logging operations and machinery information.

Logger	Stands/ Harvest Units	Logging Machines		
		Feller Buncher	Loader	Skidder
1	2/9	TC[1] 720	Prentice	JD[1] 648GIII (2)
2	5/9	TC 720	Prentice 384	JD 648GIII (2)[2]
3	5/6	JD 643J	TC 240B	JD 548GIII

[1]TC stands for TigerCat and JD stands for John Deere.
[2]Logger 2 did not work full time with 2 skidders, 2nd skidder alternated with another crew.

Table 2.2. – Explanatory variables used in the full model of the regression analysis to estimate daily production.

Variable	Description
FB	Feller buncher productive machine hours (PMH/day)
LD	Loader productive machine hours (PMH/day)
SkTot	Total skidder productive machine hours (PMH/day)[1]
SkDist	Total skidder travel distance (Km/day)
Nmach	Number of logging machines operating[2]

[1]In a 2 skidder crew, SkTot is equal to the sum of the skidders PMH.
[2]Nmach = 3 for a 1 skidder operation and Nmach = 4 for a 2 skidder operation.

Table 2.3. – Dummy variables for logging crew effects on daily logging production introduced in the full regression model.

Variable	Description
FBL2	Logger 2 feller buncher PMH effect
FBL3	Logger 3 feller buncher PMH effect
LDL2	Logger 2 loader buncher PMH effect
LDL3	Logger 3 loader buncher PMH effect
SkTotL2	Logger 2 total skidder PMH effect
SkTotL3	Logger 3 total skidder PMH effect
SkDistL2	Logger 2 daily skidder travel distance effect
SkDistL3	Logger 3 daily skidder travel distance effect
NmachL2	Logger 2 number of logging machines operating effect
NmachL3	Logger 3 number of logging machines operating effect

Table 2.4. ─ Summary of the harvest units and logging crew production parameters.

Logger	Harvest Unit	Area (ha)	Volume Removed (Tonnes/ha)	Machines (No.)	Production (Tonnes/shift)	Skidder Travel (Km/day)
1	1	9.19	122	4	188	21.5
1	2	3.07	65	4	178	25.5
1	3	7.84	139	4	215	33.6
1	4	4.64	100	4	177	13.5
1	5	19.22	115	4	221	33.5
1	6	11.34	15	4	234	20.2
1	7	7.26	158	4	219	40.7
1	8	8.55	71	4	209	20.8
1	9	3.19	133	4	224	36.4
2	10	23.35	74	4	189	18.4
2	11	12.74	106	4	209	23.9
2	12	10.45	92	4	191	36.6
2	13	4.86	108	4	147	28.9
2	14	13.99	32	4	172	24.2
2	15	10.40	42	4	177	19.2
2	16	11.77	51	4	203	25.4
2	17	10.51	159	4	222	20.7
2	18	12.86	90	4	202	20.9
3	19	11.79	135	3	144	20.1
3	20	3.83	39	3	136	28.0
3	21	6.60	49	3	125	20.6
3	22	19.42	55	3	140	23.9
3	23	25.08	85	3	146	34.0
3	24	4.65	123	3	130	26.2
			Means			
1		8.26	102		209	29.9
2		12.33	84		195	25.3
3		11.90	81		141	26.6
Overall		**10.69**	**90**		**184**	**27.1**

Table 2.5. — Summary of the productivity analysis parameters.

	Harvest	Shift	PMH/Shift			UR (%)		
Logger	Unit	(SMH)	FB	LD	SK	FB	LD	SK
1	1	11	6.2	6.1	5.5	57	55	50
1	2	11	6.3	6.6	5.3	57	60	48
1	3	11	6.2	7.1	7.3	57	65	66
1	4	11	3.3	4.0	4.2	30	37	38
1	5	11	7.2	7.6	8.3	66	69	76
1	6	11	5.2	5.2	4.8	47	47	43
1	7	11	5.9	7.6	7.8	54	69	71
1	8	11	4.3	4.3	4.2	39	39	38
1	9	11	6.5	7.4	7.8	59	67	70
2	10	10	5.2	5.5	3.4	52	55	34
2	11	10	5.5	5.1	5.4	55	51	54
2	12	10	5.0	4.7	6.8	50	47	68
2	13	10	4.4	4.2	5.0	44	42	50
2	14	10	5.0	3.6	4.5	50	36	45
2	15	10	4.6	3.8	3.8	46	38	38
2	16	10	5.1	4.3	5.2	40	43	52
2	17	10	3.8	4.2	4.2	38	42	42
2	18	10	1.4	3.3	4.2	6	33	42
3	19	10	3.4	4.2	4.2	34	42	42
3	20	10	5.0	5.3	3.6	50	53	36
3	21	10	3.7	3.4	3.0	37	34	30
3	22	10	3.2	3.9	3.9	32	39	39
3	23	10	4.8	5.6	6.4	48	56	64
3	24	10	4.6	5.1	4.6	46	51	46
			Means					
1			6.2	6.7	6.7	56	61	61
2			4.6	4.3	5.0	46	43	50
3			4.0	4.7	4.8	40	47	48
Overall			**4.9**	**5.2**	**5.5**	**47**	**50**	**53**

Table 2.6. – Correlation matrix of daily logging production and the explanatory variables.

Variables	Production	FB	LD	SkTot	SkDist	Nmach
Production	**1.000**	0.748**	0.857**	0.742**	0.702**	0.089
FB	0.748**	**1.000**	0.842**	0.736**	0.644**	0.099
LD	0.857**	0.842	**1.000**	0.834**	0.760**	0.069
SkTot	0.742**	0.736**	0.834**	**1.000**	0.929**	0.298**
SkDist	0.702**	0.644**	0.760**	0.929**	**1.000**	0.219*
Nmach	0.089	0.099	0.069	0.298**	0.219*	**1.000**

Probabilities levels of significance: * < 0.10; ** < 0.01

Table 2.7. – ANOVA table for the selected regression model of daily production (tonnes).

Source	DF	Sum of Squares	Mean Square	F-value	P > F	
Model	2	402922	201461	190.53	< 0.0001	
Error	134	141687	1057.36			
Total	136	544609			**R^2 = 0.7398**	
Variable	Estimate	Std. Error	t-value	P > t	90% Conf. Limits	
Intercept	21.2596	7.2283	2.94	0.0039	9.2873	33.2320
LD	21.6926	1.9253	11.27	< 0.0001	18.5034	24.8816
SkDist	0.5998	0.3345	1.79	0.0753	0.0457	1.1539

Table 2.8. ANOVA table and parameter estimates for the selected regression model to test for logging crew effect on daily logging production (tonnes).

Source	DF	Sum of Squares	Mean Square	F-value	P > F	
Model	7	442973	63282	100.06	< 0.0001	
Error	122	77161	632.46			
Total	129	520134			**R^2 = 0.8517**	

Variable	Estimate	Std. Error	F-value	P > F	90% Conf. Limits	
Intercept	-16.2022	10.6225	2.33	0.1298	-33.81	1.40
LD	27.5100	1.4911	340.39	< 0.0001	25.04	29.98
FBL2	4.6691	1.8451	6.40	0.0127	1.61	7.73
FBL3	-10.1568	3.7278	7.42	0.0074	-16.34	-3.98
LDL3	11.3205	5.0893	4.95	0.0280	2.89	19.76
SkTotL3	-10.8730	3.6643	8.80	0.0036	-16.95	-4.80
NmachL2	6.7819	3.2606	4.33	0.0396	1.38	12.18
NmachL3	19.5970	5.6327	12.10	0.0007	10.26	28.93

Chapter 3. Using Logging Machine GPS Positional Data to Map Harvested Areas

Abstract

This study was designed to evaluate the use of the Multidat datalogger to track logging operations by collecting Global Positioning System (GPS) positional data on the skidders and feller bunchers. The objective was to evaluate the harvest areas generated by the positional data collected. Data were collected from 4 different logging crews conducting thinning operations in 19 stands in Alabama. The crews were composed of one loader, one feller buncher, and one or two skidders. Harvested areas were defined as areas where the logging machines trafficked as identified from the positional data. The harvested areas shapefiles were generated by digitization following the edges of the machinery positional points. Three approaches were applied to evaluate the differences between harvested and the original shapefiles of the stand areas provided by the landowners (area ratio, points ratio, and skeletonization) and pointed to significant differences between the two shapefiles. Relative area differences were not influenced by logging crew differences but tended to be smaller for larger stand sizes. Differences were difficult to attribute specifically to positional errors or inaccuracies in the original shapefiles. Suitable methods to establishing the nature of these differences were beyond the scope of the project. Overall the results indicate that the method has potential to provide operational maps with little labor input. Promising applications for the technique may be as an accounting system that the logging contractor can use to document activities, as an update to GIS systems to highlight potential issues with stand maps, and as a first map for landowners with little mapping information.

Introduction

The implementation of precision technologies to manage, plan, document and monitor forestry activities can bring substantial benefits to foresters, loggers, and landowners (Holley 2001, Taylor et al. 2006). Benefits in logging operations include reduction of operational costs and minimization of environmental impacts due to machinery operations on the forest stand (Kopka and Reinhardt 2006). Applications include the documentation, mapping, and evaluation of logging machine activities. Cordero et al. (2006) used GPS technology to evaluate logging machinery performance by generating surface process grids and combining them with inventory data to generate forest yield maps. McDonald and Fulton (2005) used GPS to generate traffic maps on a tree-length harvesting operation and converted positional data collected from skidders into time study information. Holley (2001) evaluated the ability of precision technologies to assist machine operators to avoid trespassing and to help determine skid trail and logging deck locations.

The applicability of GPS technology in forestry may be limited due to the effect of forest canopy and other adverse conditions on capturing GPS satellite signals. A closed forest canopy may block GPS satellite signals and decrease the accuracy of positional data (Bolstad et al. 2005). Veal et al. (2001) reported that GPS accuracy under forested conditions can significantly vary with regard to forest canopy density. The closer the canopy, the lower the GPS efficiency and accuracy in capturing positional data (Sigrist et al. 1999). Kopka and Reinhardt (2006) concluded that accuracy of GPS systems under forest canopy mainly depends on climatic aspects, slope angle, and canopy density.

This study consisted of evaluating the use of positional data from logging machines to map logging activities in pine stands. Positional data were collected on the skidders and the feller bunchers conducting thinning operations under closed canopy conditions. The objective was to develop a method to generate a map of the harvested areas from machinery GPS positional data and to evaluate these maps by comparing them to the maps of the original stand areas.

Material and Methods

Positional data were collected from thinning operations on pine plantations in Alabama using Multidat dataloggers equipped with GPS receiver. The Multidat is a machine monitoring system developed by the Forest Engineering Research Institute of Canada (FERIC) to obtain accurate information on logging machine productivity. The Multidat can record machine productive time, machine functions and movement and operator comments to help identify downtime causes. The GPS feature of the Multidat datalogger enables it to collect machine positional data and to determine the areas that have been trafficked (Brown et al. 2002).

Data were collected from June 2007 to November 2008. Data collection periods ranged from a couple of weeks to a few months, depending on the agreement with the logging contractor. A total of three logging contractors and four logging crews participated in this research. The logging crews were composed of one loader (LD), one feller buncher (FB), and one or two skidders (SK). Total information collected summed to almost one year of data (47 weeks or 177 worked days) collected from 19 harvested stands. Table 3.1 summarizes machinery information and the number of stands harvested by each crew over the data collection period.

A Multidat with a Garmin GPS 15 receiver was installed inside each feller buncher and skidder. Under forest conditions, the GPS 15 has an accuracy of less than 15 meters from true position (GPS 15 Technical Specifications). For the feller bunchers a position was recorded at 30 seconds intervals and for the skidders a position was recorded based on a distance interval of 4 meters. The different configuration for the skidder was an attempt to calculate total distance traveled by the skidder by summing the number of data points collected.

GIS Data Analysis

Geographic Information Systems (GIS) analysis was conducted using ArcGIS 9, ArcMap Version 9.2. The analysis consisted of several steps starting with importation of the GPS data into ArcMap and with the evaluation of the data collected and ending with the generation of the map of the harvested areas. The GPS data were exported from the Multidat software in a point shapefile format. All the GIS data used or generated during the analyses were projected in WGS 1984 coordinate system (World Geodesic System, 1984).

GPS data were imported into ArcMap display for a visual analysis of the operations. The visual analysis of the GPS data identified machine activity in each stand and helped to identify missing data or errors in positional data. Stands with significant amounts of missing data were excluded from all the GIS analysis. The next steps of the analysis involved a series of operations to identify, delineate, and measure the harvested stands.

Harvested stands were defined as areas with positional data from either mobile logging machine. In ArcMap I used the machine positional data to locate and digitize the boundaries of the harvested stands by following the edges of the areas with high density of machine positional points. Figure 3.1 displays the process of generating the shapefiles of the harvested stands. I compared the harvested stand shapefiles to the original stand shapefiles that were provided by the landowners. Original stand shapefiles might have been photo-interpreted from aerial imagery, determined by GPS in another operation, or digitized from earlier paper maps.

A series of spatial and data management operations using ArcToolbox and the Spatial Analyst Extension in ArcGIS were conducted to compare the harvested to the original shapefiles of each stand. Original stand shapefiles were assumed to reflect the correct stand areas. The two shapefiles for each stand were compared for inconsistent (difference) and matching (intersected) areas. The intersected areas were the areas in the original and harvested stand that were certainly harvested. Areas in the original stand that were not included in the harvested stand were defined as non-harvested (NH). Over-harvested (OH) areas were areas of the harvested stand that fell outside the original stand boundary.

Non-harvested and over-harvested areas were identified and measured by spatial analysis approaches using ArcMap. The “calculate geometry” tool in ArcMap provided data to compare the shapefiles (harvested and original) and calculate the differences in area due to NH and OH. The ratio of NH and OH to the union area (union of the original and harvested stand area shapefiles) were named non-harvested area ratio (NAR) and over-harvested area ratio (OAR), respectively. This approach was named the area ratio approach.

The other approach generated an area ratio using random points and was named the points ratio approach. In ArcMap the “create random points” tool placed a specified number of points (100 points per hectare) within the union area shapefiles. The points in the NH and OH areas were counted and the ratio to total points distributed was calculated. The non-harvested points ratio (NPR) corresponded to the percentage of the random points that were placed into the NH area; the over-harvested points ratio (OPR) corresponded to the percentage of the random points that were placed into the OH area.

The paired shapefiles were also evaluated with a morphological image processing technique called skeletonization. Skeletonization is a process for reducing foreground regions in a binary image to a skeletal remnant that preserves the extent and connectivity of the original region while throwing away most of the original foreground pixels (Fisher et al. 2004). Basically the skeletonization process sequentially erodes the image down to a connected line or skeleton. The remnant skeleton is a powerful shape factor for feature recognition that contains both topological and metric information (Russ 1992). A concern of using skeletonization for shape-matching analysis is its sensitivity to minor changes in the shape of the feature (Russ 1992, Bai and Latecki 2007). Small changes such as an extra pixel or gap within the feature boundary can significantly alter the skeleton topology (Russ 1992).

Skeletonization topological information includes the number of end points and the number of nodes where branches meet (triple points) and metric information includes length and angle of the branches (Russ 1992). The number of triple points can be used to distinguish qualitatively different shapes from one another (Fisher et al. 2004). In this study I used the shape area, the skeleton length, and the number of triple points information as the parameters to compare the original and the harvested images. The parameter values were transformed (natural logarithm and square root transformations) and a t-test was applied on the differences (original-harvested) of the parameter values and transformations (Ho = 0 at $\alpha = 0.10$).

Results and Discussion

Data were lost through the study period from power source issues and satellite reception. Power source issues included blown fuses or disconnected wires. In these situations data losses could have been avoided or minimized if the interval between data downloads was shorter. Data were downloaded every 3-4 weeks. GPS data loss occurred from either poor satellite reception or problems with the external antenna. Poor satellite reception may have been a result of several factors such as satellite orbit position or canopy cover effect.

Data from 19 stands of loblolly pine plantation were analyzed. The harvested areas, the original stand areas, the intersected areas, and the union areas are presented in Table 3.2 and an example is displayed in Figure 3.2. The average of the ratio of the intersect area to original stand area for the 19 stands was 86%. The remainder is in non-harvested (NH) areas which may include areas previously harvested, sensitive areas not harvested, areas with little or no thinning activity, non-forested areas (e.g. roads and trails), and/or gaps in positional data coverage. The over-harvested (OH) areas represented machine activity in areas that were outside of the original stand boundaries. Nonparametric statistical tests using the Univariate procedure in SAS were used to evaluate the differences between original and harvested stand areas. Results of the Wilcoxon Signed Rank test and the Sign test indicated a significant difference ($\alpha = 0.10$) between original and harvested stand areas (Table 3.3).

The calculated NH and OH areas, the area ratios, and the points ratios for each stand are presented in Table 3.4. NH and OH areas ranged from 0.36 to 7.21 ha and from 0.01 to 3.75 ha, respectively. The non-harvested area ratio (NAR) ranged from 4.64% to 25.93% and averaged 11.66%. The over-harvested area ratio (OAR) averaged 6.03% ranging from 0.35% to 16.24% and tended to be greater in smaller stands (Figure 3.3). Over-harvest points ratio (OPR) ranged from 0.25% to 16.42% and averaged 6.11%, and non-harvested points ratio (NPR) ranged from 4.45 to 26.79% and averaged 11.82%. The confidence interval of the point ratio estimates indicated that NH areas were greater than zero ($\alpha = 0.10$) for all stands and OH areas were significant in all but in stand number 13 (Table 3.5).

The correlation matrix (Table 3.6) for the parameters presented in Tables 3.2 and 3.4 indicated a strong positive correlation between stand area and NH and OH areas, suggesting that NH and OH areas tended to be larger for larger stand areas. When analyzing the correlation between the area ratios (NAR and OAR) and stand area, however, these ratios are negatively correlated to stand area. This indicates that proportionally NH and OH tend to be smaller for larger stand sizes (Figure 3.3). Logging crew differences did not significantly affect the variability of OH and NH areas (Tables 3.7 and 3.8).

A summary of the results of the skeletonization is presented in Table 3.9 and an example is displayed in Figure 3.4. Results of the t-tests for the parameters differences indicated that the original and harvested images were significantly different (Ho = 0 rejected at $\alpha = 0.10$) for all the parameters and transformations tested (Table 3.10). These results indicated that overall the original and harvested images were morphologically different.

Conclusions

It is possible to generate a shapefile of the harvested areas (post-harvest map) from logging machine positional data. The comparisons of those areas to original stands pointed to issues with the data collection and analysis and likely limitations of the original stand areas. The 3 evaluation approaches (area ratio, points ratio, and skeletonization) indicated significant differences between harvested and original stands. The issue of positional error is more obvious in the assessment of over-harvested areas since those errors would likely increase as the perimeter to area ratio of the original stand increased in the smaller stands. It is also likely that not all of the estimated over-harvest is error due largely to possible inaccuracies in the original stand boundary location in the shapefile. The importance of positional errors in the non-harvested area is more difficult to detect. Non-harvested areas could be mostly generated by uneven stand conditions that reduced or precluded harvesting in portions of the original stand.

The methods most suitable to establishing the nature of the differences between the stand areas would be ground truth or point samples of completed harvest area. Both methods would have been extremely labor intensive and were not planned for in the original scope of the project. Another data source to evaluate the results could become available as new imagery that includes the harvested areas area generated.

The results indicate that the method has potential to provide operational maps with little labor input. The method does not appear to be biased with respect to original stand area and has the potential to highlight problems (NH and OH) with the original stand maps. Given the limitations it appears that the promising applications for the technique may be as an accounting system that the logging contractor can use to document activities, as an update to GIS systems to highlight potential issues with stand maps, and as a first map for landowners with little mapping information. While more accurate GPS systems could reduce the real errors it probably would not eliminate the differences between the shapefiles generated with different methods.

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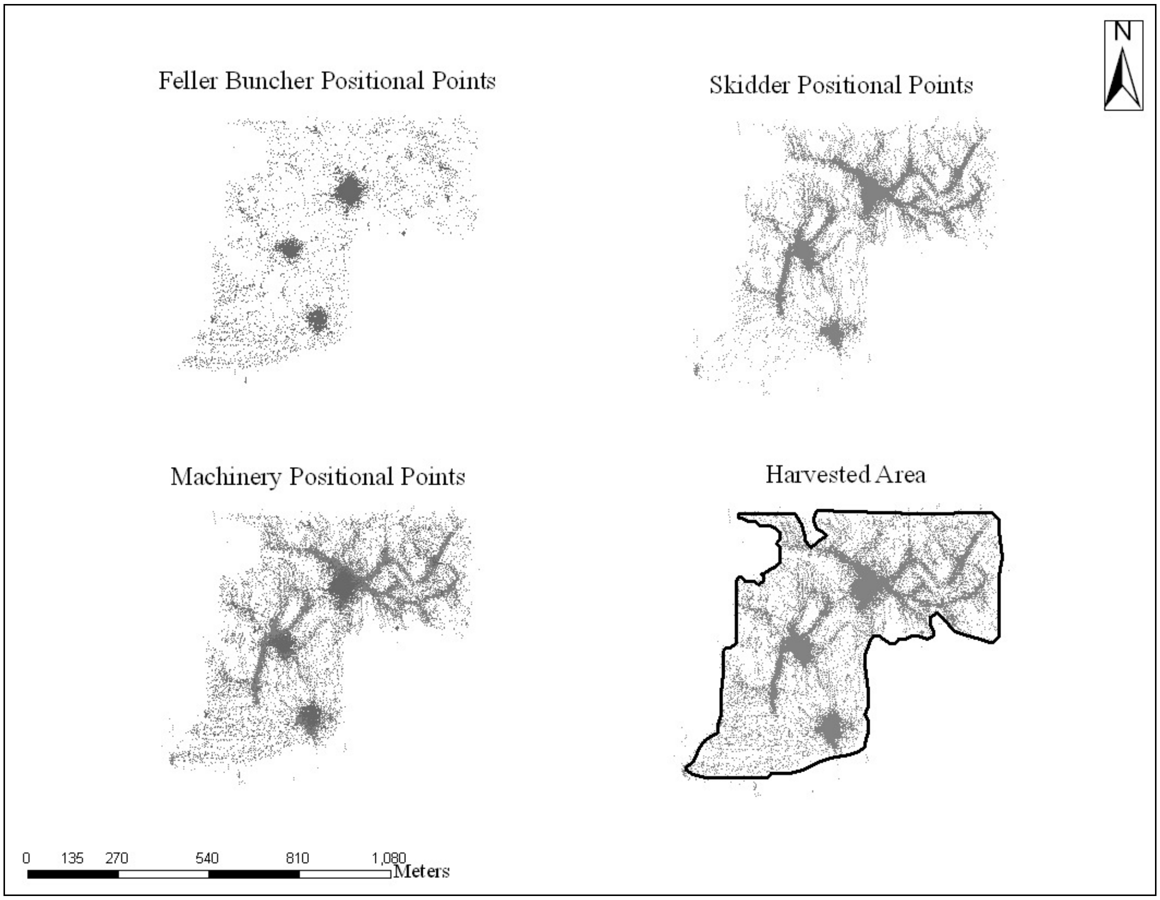

Figure 3.1. – Digitization process of generating the shapefiles of the harvested stands.

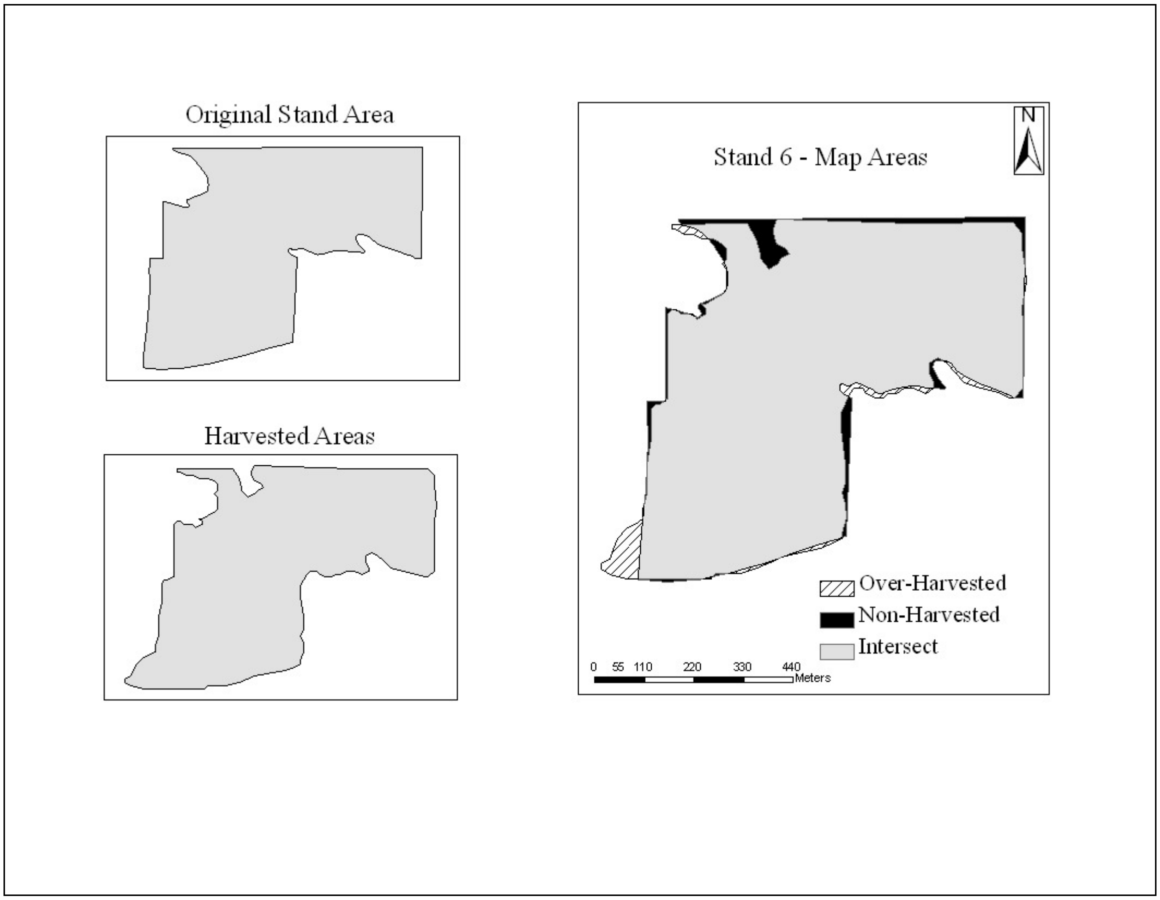

Figure 3.2. – Map areas of stand 6, including: original stand shapefile, harvested stand shapefile, and intersect, over-harvested, and non-harvested areas.

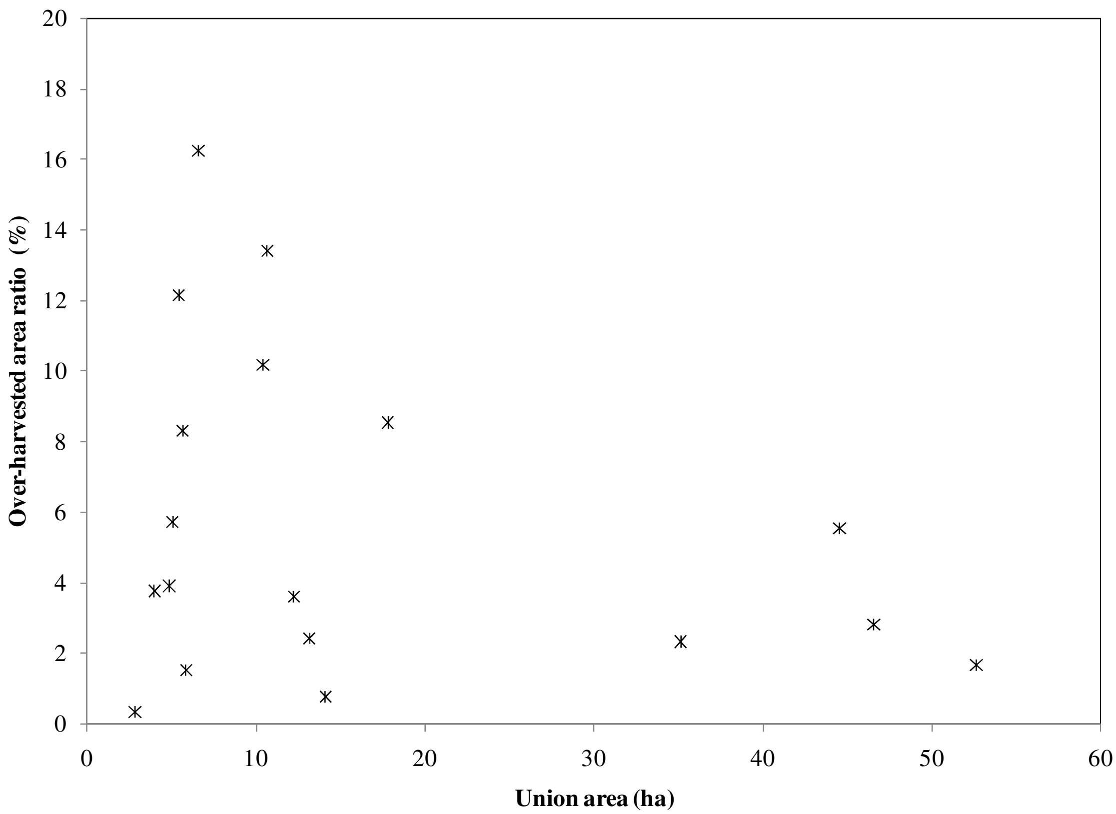

Figure 3.3. – Scatter plot of union areas vs. over-harvested area ratios (OAR).

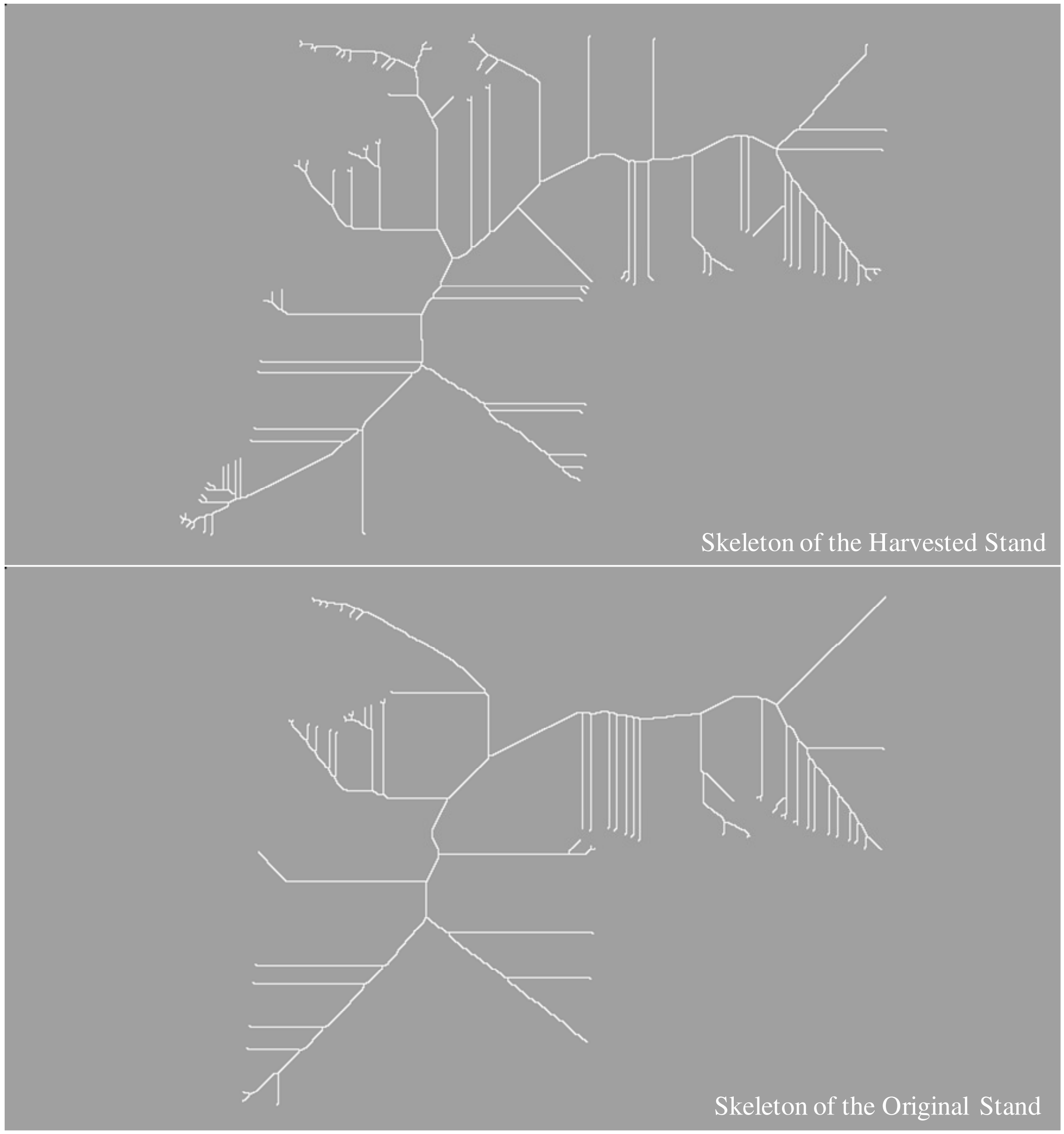

Figure 3.4. – Harvested and original skeleton images generated for stand 6.

Table 3.1. – Summary of the logging operations and machinery information.

Logger /Crew	Number of Stands	Logging Machines		
		Feller buncher	Loader	Skidder
1/1	3	TigerCat 720	Prentice	John Deere 648GIII (2)
2/1	8	John Deere 843	Prentice 384	John Deere 648GIII[1] (2)
2/2	3	TigerCat 720	Prentice 384	John Deere 648GIII[1]
				TigerCat610
3/1	5	John Deere 643J	TigerCat240B	John Deere 548GIII

[1]Crews 1 and 2 from contractor 2 did not work full time with 2 skidders, 2nd skidder alternated between the crews.

Table 3.2. – Summary of the information for each stand.

			Stand Areas (ha)				
Stand	Logger	Crew	Original	Harvested	Difference[1]	Intersect	Union
1	1	1	58.27	58.23	0.04	54.48	62.02
2	1	1	12.83	12.23	0.60	11.95	13.15
3	1	1	9.23	9.47	-0.24	8.04	10.66
4	2	1	16.28	14.74	1.54	13.22	17.80
5	2	1	4.77	4.32	0.45	3.67	5.43
6	2	1	45.23	44.31	0.92	42.00	46.54
7	2	1	5.19	4.97	0.22	4.50	5.66
8	2	1	4.67	3.59	1.08	3.40	4.86
9	2	1	13.99	6.89	7.10	6.78	14.10
10	2	1	9.35	8.98	0.37	7.92	10.41
11	2	1	34.31	33.51	0.80	32.69	35.13
12	2	2	51.73	49.55	2.18	48.68	52.61
13	2	2	2.82	2.47	0.35	2.46	2.83
14	2	2	5.77	4.93	0.84	4.84	5.86
15	3	1	11.79	11.19	0.60	10.75	12.23
16	3	1	3.83	3.45	0.38	3.30	3.98
17	3	1	5.52	5.98	-0.46	4.91	6.59
18	3	1	42.04	38.48	3.56	36.01	44.51
19	3	1	4.78	4.65	0.13	4.36	5.07

[1]Difference = Original stand area – harvested stand area.

Table 3.3. – Statistical tests results from the Univariate Procedure comparing the original and harvested areas.

Test	Statistic		P-Value	
Student's t	t	4.23	P > t	0.0006
Sign	M	9	P > M	0.0001
Signed Rank	S	85.5	P > S	0.0001

Table 3.4. – Ratio calculations for non-harvested area (NAR) and over-harvested area (OAR), and non-harvested points (NPR) and over-harvested points (OPR).

Stand	Points[1]	Non-harvested			Over-harvested		
		NH (ha)	NAR (%)	NPR (%)	OH (ha)	OAR (%)	OPR (%)
1	6202	3.79	6.11	6.36	3.75	6.05	5.98
2	1315	0.89	6.77	6.59	0.32	2.43	2.26
3	1066	1.19	11.16	11.09	1.43	13.41	13.59
4	1780	3.06	17.19	17.36	1.52	8.54	8.56
5	543	1.1	20.26	20.1	0.66	12.15	12.56
6	4654	2.23	4.79	4.76	1.31	2.81	2.75
7	566	0.69	12.19	11.77	0.47	8.30	8.48
8	486	1.26	25.93	26.79	0.19	3.91	4.47
9[2]	1410	7.21	51.13	51.19	0.11	0.78	0.73
10	1041	1.42	13.64	14.01	1.06	10.18	10.32
11	3513	1.63	4.64	4.45	0.82	2.33	2.38
12	5261	3.05	5.80	5.94	0.88	1.67	1.68
13	283	0.36	12.72	13.11	0.01	0.35	0.25
14	586	0.93	15.87	16.07	0.09	1.54	1.55
15	1223	1.04	8.50	8.77	0.44	3.60	3.43
16	398	0.53	13.32	14.29	0.15	3.77	4.18
17	659	0.61	9.26	9.82	1.07	16.24	16.42
18	4451	6.02	13.53	13.69	2.47	5.55	5.43
19	507	0.42	8.28	7.88	0.29	5.72	5.67

[1]Number of total random points generated (100 points/ha).
[2]Stand 9 was considered an outlier and excluded from the average calculations.

Table 3.5. – The 90% confidence interval of points ratio estimates (NPR and OPR).

Stand	Points[1]	NPR	L90[2]	U90[2]	OPR	L90[2]	U90[2]
		%					
1	6202	6.36	5.85	6.87	5.98	5.49	6.48
2	1315	6.59	5.46	7.71	2.26	1.58	2.93
3	1066	11.09	9.51	12.67	13.59	11.86	15.31
4	1780	17.36	15.88	18.83	8.56	7.47	9.66
5	543	20.1	17.27	22.93	12.56	10.22	14.90
6	4654	4.76	4.25	5.28	2.75	2.35	3.14
7	566	11.77	9.54	14.00	8.48	6.55	10.41
8	486	26.79	23.48	30.09	4.47	2.93	6.01
9	1410	51.19	49.00	53.38	0.73	0.36	1.10
10	1041	14.01	12.24	15.78	10.32	8.77	11.87
11	3513	4.45	3.88	5.03	2.38	1.96	2.81
12	5261	5.94	5.40	6.47	1.68	1.39	1.97
13	283	13.11	9.81	16.41	0.25	-0.24	0.74
14	586	16.07	13.57	18.56	1.55	0.71	2.39
15	1223	8.77	7.44	10.10	3.43	2.58	4.29
16	398	14.29	11.40	17.18	4.18	2.53	5.84
17	659	9.82	7.91	11.73	16.42	14.04	18.79
18	4451	13.69	12.84	14.53	5.43	4.87	5.99
19	507	7.88	5.91	9.84	5.67	3.98	7.36

[1]Number of total random points generated (100 points/ha).
[2]Lower and upper 90% confidence interval limits.

Table 3.6. – Correlation matrix of stand areas and stand differences variables

Variables	OPR	OAR	OH	NPR	NAR	NH	Union	Harvested	Intersect	Area
Area	-0.297	-0.283	0.725**	-0.535*	-0.541*	0.776**	0.999**	0.999**	0.998**	**1.000**
Intersect	-0.308	-0.294	0.708**	-0.560*	-0.566*	0.745**	0.999**	0.999**	**1.000**	0.998**
Harvested	-0.284	-0.269	0.733*	-0.553*	-0.559*	0.757**	0.999**	**1.000**	0.999**	0.999**
Union	-0.275	-0.260	0.748**	-0.528*	-0.534*	0.787**	**1.000**	0.999**	0.999**	0.999**
NH	-0.088	-0.074	0.784**	-0.090	-0.091	**1.000**	0.787**	0.757**	0.745**	0.776**
NAR	0.227	0.200	-0.259	0.998**	**1.000**	-0.091	-0.534*	-0.559*	-0.566*	-0.541*
NPR	0.218	0.190	-0.255	**1.000**	0.998**	-0.090	-0.528*	-0.553*	-0.560*	-0.535*
OH	0.245	0.262	**1.000**	-0.255	-0.259	0.784**	0.748**	0.733*	0.708**	0.725**
OAR	0.999**	**1.000**	0.262	0.190	0.200	-0.074	-0.260	-0.269	-0.294	-0.283
OPR	**1.000**	0.999**	0.245	0.218	0.227	-0.088	-0.275	-0.284	-0.308	-0.297

Probabilities levels of significance: * < 0.10; ** < 0.01

Table 3.7. – Analysis of variance for OAR by logging crew using Npar1Way Procedure.

Source	DF	Sum of Squares	Mean Square	F-value	P > F
Among	3	70.89	23.63	1.1890	< 0.3497
Within	14	278.23	19.87		
Crew	N	Mean			
1	3	7.30			
2	8	6.24			
3	3	1.83			
4	4	7.82			

Table 3.8. – Analysis of variance for NAR by logging crew using Npar1Way Procedure.

Source	DF	Sum of Squares	Mean Square	F-value	P > F
Among	3	58.21	19.40	0.5519	< 0.6552
Within	14	492.21	35.16		
Crew	N	Mean			
1	3	8.01			
2	8	13.06			
3	3	12.36			
4	4	11.10			

Table 3.9. – Summary of the skeletonization analysis parameters.

	Original			Harvested		
Stand	Area	Length	Triple Pts	Area	Length	Triple Pts
1	61810	2201	21	61688	2566	30
2	60228	1074	5	57411	1110	4
3	106587	5623	52	109663	5691	59
4	20797	1628	28	18775	2295	60
6	143092	4619	54	140276	5686	67
7	69083	3310	42	65669	3810	45
8	44795	2979	44	34194	3431	60
9	49360	3730	69	47398	4450	88
10	207600	6800	47	202958	6539	43
11	120938	5479	69	115842	4715	64
12	138988	2568	12	122026	2532	26
13	49595	735	10	42455	1204	16
14	99039	9342	131	94069	8729	131
15	157357	4258	23	141789	5848	44
16	52551	2263	22	56909	4389	53
17	65979	3708	57	60391	3670	54
18	73584	3296	50	71669	3331	45
19	61810	2201	21	61688	2566	30

Table 3.10. – T-test results for the comparative analysis between original and harvested skeletonization parameters.

T-test for parameter values			
Parameter	DF	t-value	P-value
Area	16	4.79	0.0002
Length	16	4.12	0.0008
Triple points	16	4.88	0.0002
T-test for log transformed values			
Parameter	DF	t-value	P-value
Area	16	4.66	0.0003
Length	16	3.89	0.0013
Triple points	16	3.31	0.0045
T-test for square root transformed values			
Parameter	DF	t-value	P-value
Area	16	5.27	0.0001
Length	16	4.15	0.0008
Triple points	16	4.64	0.0003

Chapter 4. Using GPS and GIS Technologies to Develop Harvest Planning Tools

Abstract

The objective of harvest planning is to maximize machinery utilization, increase machinery productivity, reduce harvesting costs, and minimize environmental impacts. Planning includes the location of skid trails and logging decks which can have significant impact on harvesting productivity and costs. Trails and decks should be planned together in an attempt to minimize skid distances and harvest impacts. The objective of this study was to develop Geographic Information Systems (GIS) based techniques to assist harvest planning using logging productivity data, machinery Global Positioning System (GPS) positional data, and mapping information of 24 harvesting operations in Alabama. Techniques included the estimation of a wander factor for total skid travel distance calculation and the estimation total skidding time of a harvest. The average wander factor (1.22) was applied to estimate total skidding time of a harvest. Results showed that estimated times were on average 33% shorter than actual skidding times. The techniques presented in this study showed some limitations, but also showed a potential as analytical tools to help loggers and foresters make better decisions when planning harvesting operations.

Introduction

Logging planning combines all possible harvesting methods and systems, identifies the constraints and available resources, and adapts all these variables to the forest stand conditions. In planning an attempt is made to anticipate and prevent events that may interfere with completing the harvest in the pre-determined amount of time and cost. A basic logging plan should provide aesthetic, economical, and logistical benefits. Planning should include preparing the site for harvesting, determining the best time to harvest, choosing the proper equipment, and designing skid trails and logging deck layout. These practices can potentially minimize site impacts and increase logging productivity (McKee et al. 1985). Location of decks and skid trails is a crucial component of a logging plan which can impact harvesting costs and environmental aspects of the harvest (Contreras and Chung 2007). Skid distance is the single most significant logging variable affecting skidder productivity and can have a significant impact on harvesting costs (Brinker et al. 1996, Kluender et al. 1997, Folegatti et al. 2007). Deck and skid trail location should be planned simultaneously in an attempt to minimize skid distances.

The use of precision technologies, more specifically GPS and GIS, can assist logging planners to determine the best location of skid trails and decks based on stand characteristics and skid distance calculations. Recent examples of the application in logging include use of GPS based automated time study system to measure skid cycle distances (McDonald and Fulton 2005). Folegatti et al. 2007 used consumer GPS receivers to calculate skid cycle distances in thinning operations. Contreras and Chung (2007) developed a model that used raster-based GIS data and incorporated slope effect into straight line distance calculations to select deck locations that minimized total skid distances. Skidder travel distances may be estimated by application of a wander factor on the estimations of skidder straight distances. A skid distance wander factor is the ratio of the actual skidder travel distance to the straight (shortest path) skidder distance (Fjeld et al. 2000 and Donnelly 1978) and may be used to assess skidding productivity by estimating the actual skidder travel distance (cumulative travel distance per harvest).

The application of GPS and GIS technologies to logging operations may contribute to easier and cheaper harvest planning, which hopefully will make planning more likely. Harvest plans built with GPS and GIS support may improve the results and documentation of logging operations. The objective of this study was to develop GIS based techniques to assist harvest planning using logging productivity data, machine positional data, and mapping information. Specifically I attempted to calculate a skid distance wander factor to estimate the actual skidder travel distance. Actual and straight skidder travel distances for the wander factor calculation were estimated using skidder positional data, mapping, and logging productivity information. I also attempted to develop a technique to estimate total skidding time of a harvest.

Material and Methods

This study was conducted using GPS data, mapping information, and harvesting productivity information of three logging crews performing thinning operations on pine plantations in Alabama. The logging crews were composed of one loader (LD), one feller buncher (FB), and one or two skidders (SK) (Table 4.1). Stand maps and shapefiles were usually provided by the loggers or landowners. The GPS and the productivity data were collected using Multidat dataloggers installed in the machines. The dataloggers were set up to collect information on machine operating hours for all the machines and to collect GPS data from the skidders and feller bunchers. Data from 12 different stands were collected over periods that ranged from a few days to several weeks. The data were processed and analyzed using Excel spreadsheets, the Multidat Software, and ArcGIS Version 9.2.

GIS Data Sources

The data used for the GIS analyses included the positional data from the skidders, stand information (stand area shapefiles), and the digital elevation models (DEM). The GPS data from the skidders were exported into point shapefile format to be processed and analyzed in ArcMap. The GPS receivers were set up to collect a point every 4 meters travelled by the skidders. For most stands the original shapefile of the area was provided by the landowner. For the remaining stands I digitized a shapefile of the area using Digital Ortho Quarter Quads (DOQQ). I also digitized the shapefile of the harvested areas (harvested area shapefile) by following the edges of the areas with high density of machine positional points. For the analysis I used the original shapefiles, which were assumed to represent the correct stand area. The 30 meter resolution DEMs were downloaded from the water information website of the Alabama Cooperative Extension System (http://www.aces.edu/waterquality/). The source of the DEM data was the Alabama Land and Water Resource. DEMs were projected on WGS 1984 UTM Zone 16 North.

GIS Analysis

The GIS analyses consisted of 3 steps: calculate the actual total skidder travel distances using the positional data (total skidder travel distances in km/harvest); map the areas where the skidders operated; and calculate the straight and the slope total skidder travel distances (km/harvest) using the Spatial Analyst Extension for ArcGIS.

To calculate the actual skidder travel distances the positional data were converted from latitude and longitude coordinates to Universal Transverse Mercator (UTM) coordinates (X and Y) with the "calculate the geometry" tool in ArcMap. After conversion the distance between points was calculated using Euclidean geometry. Total actual skidder travel distance was the sum of all the distances between positional points in a harvest.

The areas where the skidders operated were assumed to be harvested areas and were mapped using ArcMap. The harvested area corresponding to each logging deck was called a harvest unit. Logging decks were located by displaying the skidder positional data and identified as the areas with the greatest concentration of skidder positional points (Figure 4.1). Stands were divided into the number of harvest units that equaled the number of decks identified. Harvest units were identified using the "select by attributes" tool in ArcMap that associated skidder positional data to the nearest deck. The selected areas were digitized to create a harvest unit shapefile. Figure 4.2 shows a stand split into 7 harvest units. I related the production data to the time stamped on the GPS data to calculate the production rate for each of the harvest units.

I applied two methods to estimate total skid travel distance during the harvest of each harvest unit. The primary method was the straight distance calculation. The harvest unit shapefile was converted to raster format so that each cell represented the area that supplied one skid load of wood. The number of raster cells per harvest unit equaled the total harvest volume divided by the estimated skid load size (Table 4.1). Skidder travel distance was estimated by assuming that the skidder would travel a straight round trip between each raster cell and the center of the logging deck. The Spatial Analyst distance calculator calculated the straight line distance from every cell to the center of the deck. The Zonal Statistics tool on the Spatial Analyst Extension calculated the minimum, maximum, average, and total straight distance. The straight skidder distance traveled during the harvesting was equal to twice the calculated total straight distance (round trip distance).

Next I added a slope factor to the skidder travel distances. This method is referred as the slope distance calculation. The Spatial Analyst Surface Analysis tool calculated the slope of the harvest unit areas using the DEM and raster cells were classified into 1% slope increment classes. I converted slope information of each raster cell into slope multipliers using trigonometric relationships. The steeper the slope, the greater the multiplier and its effect on skidder travel distances. The Spatial Analyst distance calculator calculated the slope distance from every cell in the harvest unit area to the center of the deck using the “cost weighted” tool and the slope raster file as the “cost raster” file. The Zonal Statistics tool on the Spatial Analyst Extension calculated the minimum, maximum, average, and total slope distance. The slope skidder distance traveled during the harvesting was equal to twice the calculated total slope distance (round trip distances).

Skid Distance Wander Factor

The wander factor (w) is the ratio of the actual skid travel distance to the shortest path (Donnelly 1978, Fjeld et al. 2000). Sundberg and Silversides (1996) called it the "winding factor" and reported a range for this ratio from 1.3 to 1.6 for forest machines. I calculated a wander factor for the straight distances (w_{st} = actual/straight) and for the slope distances (w_{sl} = actual/slope) using the data from all 12 stands. The wander factors were applied to adjust the straight and the slope distances to reflect the actual skidder travel distance by multiplying these distances by their respective wander factors.

GIS Tool for Estimating Total Skidding Time

The technique to estimate total skidding time used harvest unit and skidder information (wood volume, total area, area shapefile, and skid load size) to calculate skidder travel distances. The technique combined this information with skidder productive data (travel distance/productive machine hour (PMH), tonnes/PMH, schedule machine hours (SMH), and utilization rate (UR)) to estimate the number of worked days necessary to complete the skidding of a harvest. Table 4.2 presents a description of the steps of this technique.

Results and Discussion

GPS and machine productivity data from thinning operations in 12 stands of pine plantations were used in the analyses. A total of 24 logging decks and 24 harvest units were identified within the 12 harvested stands (Table 4.1). The data set represented a total of 115 days of harvesting operations. A summary of the productivity data on a harvest unit basis is presented in Table 4.3. An average harvest unit had an area of 10.7 hectares and 946 tonnes of wood removed (88.4 tonnes/ha). Skidder mean productivity was 32 tonnes/PMH and overall UR was approximately 53%.

Skidder Travel Distance and Wander Factor Calculations

The skidder travel distances and the wander factors are presented in Table 4.4. Slope distances were on average 5% longer than straight distances indicating a small slope impact on the skidder path during operations. Slope surface analysis showed that most of the harvested areas were in terrain with slopes of 10% or less. The calculation of slope may have been limited by the low resolution of the DEM used (30 meters) which may not accurately describe the actual terrain conditions (Contreras and Chung 2007).

The actual skidder travel distance was on average longer than the straight and the slope distances (Table 4.4). The actual skidder travel distance accounted not only for the effect of slope but it also included other logging variables (e.g. skid trails, stream crossings and other natural obstacles, etc.) that may alter the skidder path during operations and result in distances longer than the straight line path.

The wander factor was estimated for both the straight and the slope distances, as previously described in the methodology using the data from all 24 harvest units. The average wander factors were 1.22 and 1.15 for straight and slope distances, respectively (Table 4.4). I used the estimated wander factor to adjust the straight and slope distances to reflect the actual skidder travel distance. The adjusted straight distances (AStD) and the adjusted slope distances (ASlD) are presented in Table 4.5. Adjusted distances considerably fluctuated in relation to actual distances with ratios (actual/adjusted) ranging from 0.55 to 2.81. On average adjusted distances were about 15% shorter than actual distances. A paired t-test to compare AStD and ASlD indicated no significant difference (p-value = 0.4155). Since no statistical difference was found between AStD and ASlD, I decided to use only AStD for the estimation of total skidding time.

Estimating Total Skidding Time

The technique to estimate total skidding time (total worked days required to complete a harvest) was a function of inventory, logging productivity data (PMH and UR), and mapping information. The values of PMH and UR used for the estimation were the average values for each logging crew. The work shift (SMH/day) was assumed to be 11 hours for logger 1 and 10 hours for loggers 2 and 3. Table 4.6 compares the actual skidding times (AST), from gross production data, to the estimated skidding times (EST).

A paired T-test performed to statistically compare AST and EST indicated a significant ($\alpha = 0.10$) difference between the two values (Table 4.7). For all the harvest units EST values were smaller than AST and on average EST was 33% shorter than AST. Figure 4.3 displays the distribution of the ratio (EST/AST) for the harvest units. Smaller values of EST were to be expected since skidder travel distances used for EST calculation were the adjusted straight distances (AStD = w_{st}*straight distance). The straight distance as previously described in the methodology is the sum of the distances (round trip) from every cell in the stand to the center of the logging deck and it accounts only for skidder productive time. Skidder downtime during operations (e.g. non-skidding travel on the deck or in the woods) is present in AST, but it is not included on the calculation of EST. Omitting skidder downtime contributed to the underestimation of total skidding time.

Conclusions

The main object of this study was to develop GIS based techniques to assist harvest planning. The developed techniques presented some limitations but resulted in analytical tools to plan harvest operation.

The estimated wander factor included GPS data from skidder operations on the thinning of 12 different loblolly pine plantation stands on gentle slopes. The result was a general factor for these conditions that can be applied to estimate total skid travel distance in a harvest by adjusting the straight distances calculated using GIS software or other means. The skidding time technique underestimated actual skidding time reflecting the effect of omitting skidder downtime from the estimation.

The methods presented in this study may also be used to design a GIS tool to determine logging deck locations in irregularly shaped harvest units as a function of skid travel distance per volume removed (km/tonne). The tool would use harvest unit and skidder information (wood volume, total area, area shapefile, and skidder load size) for straight distance calculation (refer to Steps 1-4 in Table 4.2) and an empty point shapefile created to mark the location of the center of the deck (which could be anywhere within the harvest unit boundaries). Using the editor tool in ArcMap to create a new feature, the location of the center of the logging deck is selected and total straight distance traveled is calculated. Possible logging deck locations may be pre-selected based on other criteria for selecting deck location (e.g. topography, terrain conditions, and existing roads). The tool can then be applied iteratively to determine the pre-selected location that minimizes the distance per volume ratio (Figure 4.4). The objective would be to use the distance per volume ratio (Km/tonne) as the decision parameter to determine improved deck location. A limitation of this technique is that users must predetermine harvest units serviced by a single deck.

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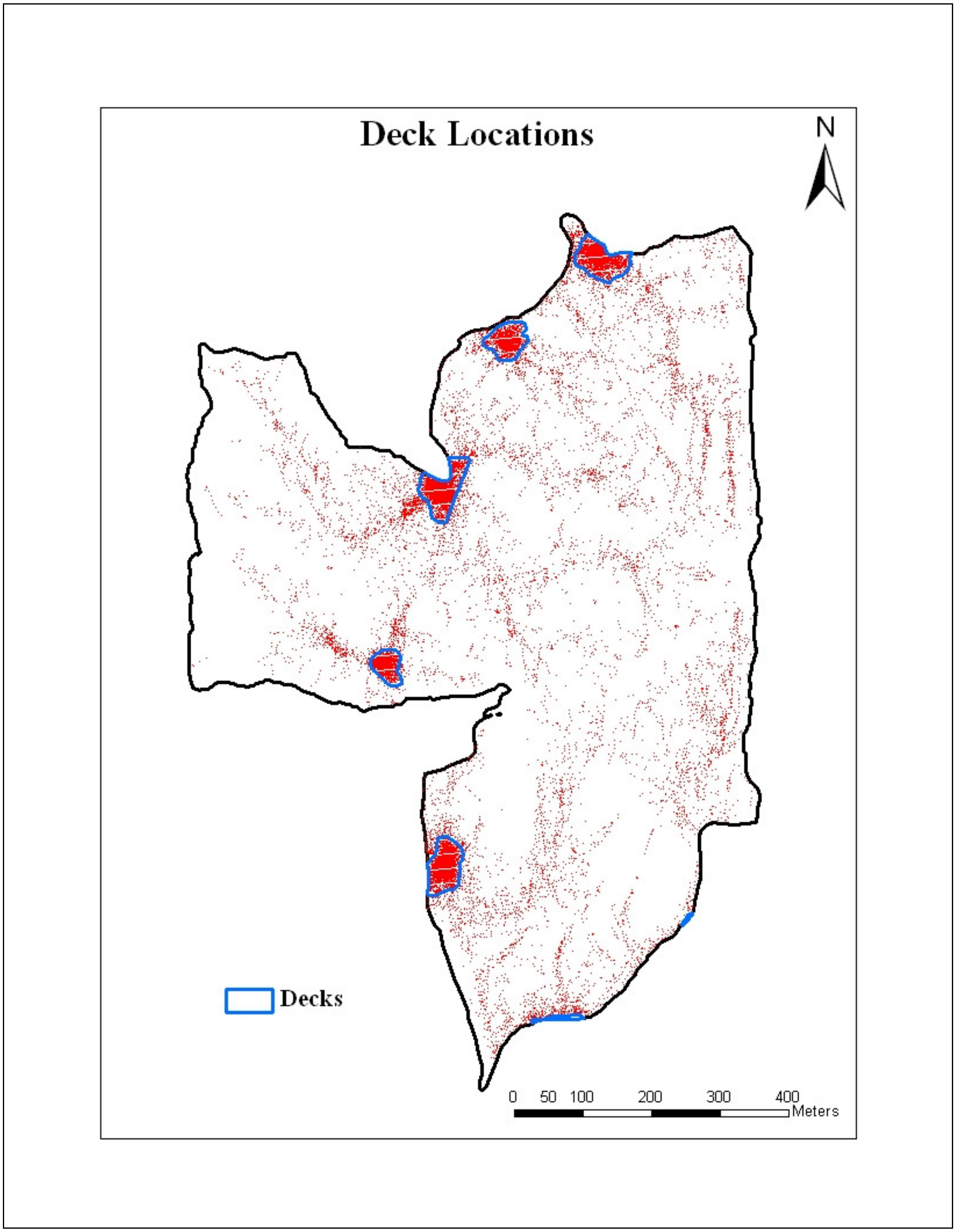

Figure 4.1. — Location of the logging decks.

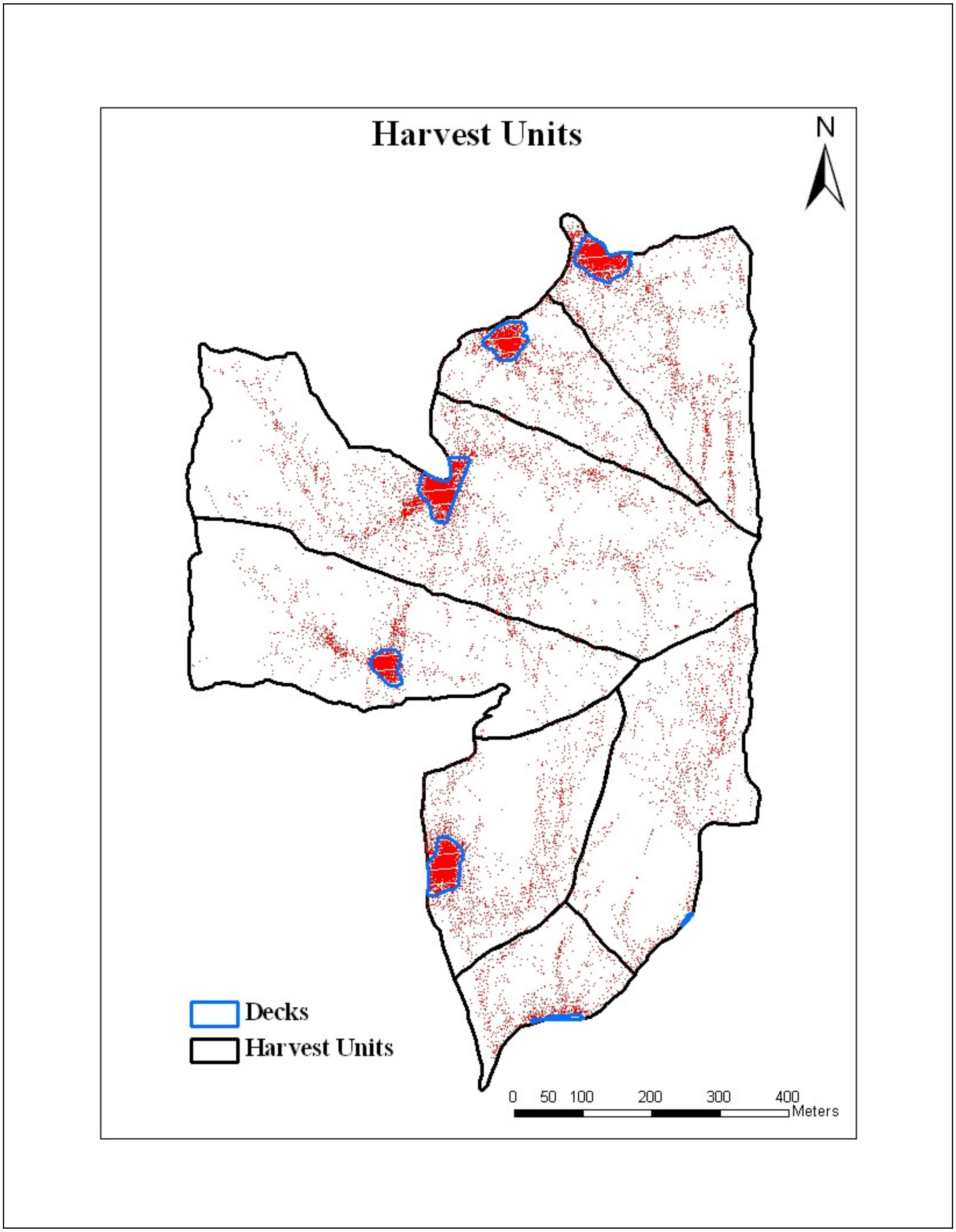

Figure 4.2. — Stand divided into harvest units (harvest units 1 through 7) based on the relationship between positional data and logging deck location.

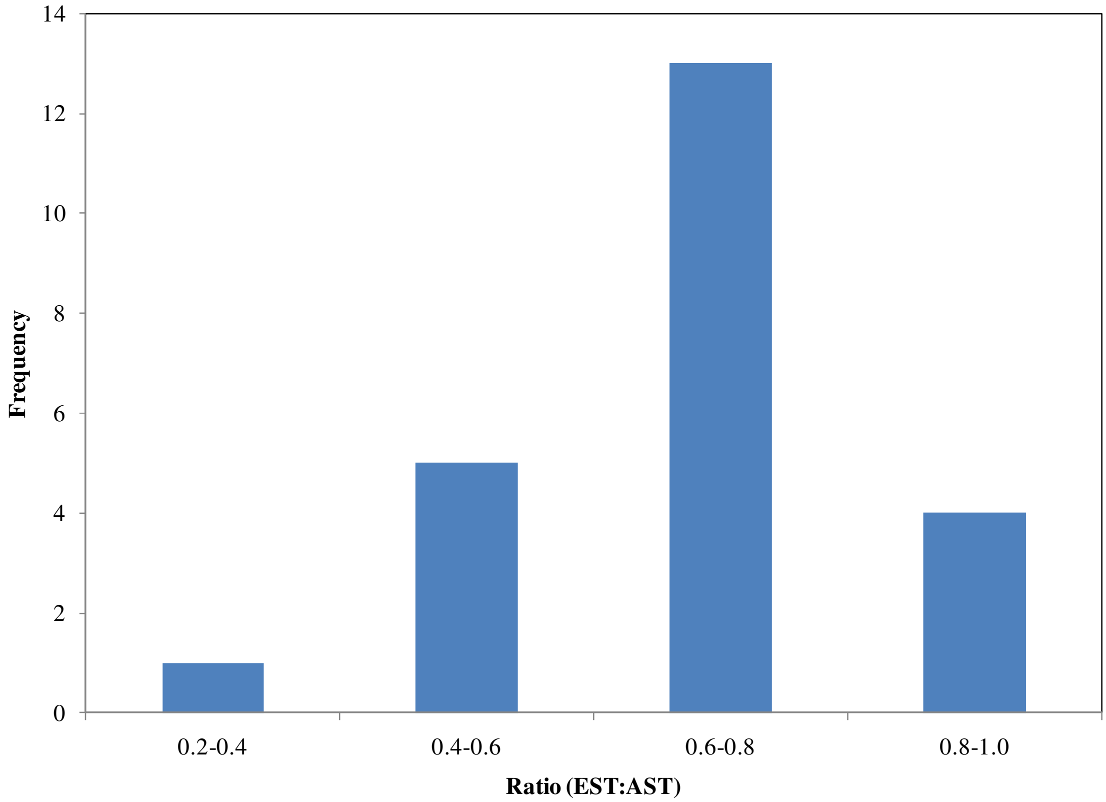

Figure 4.3. – Frequency distribution of the ratio of estimated skidding time (EST) and actual skidding time (AST).

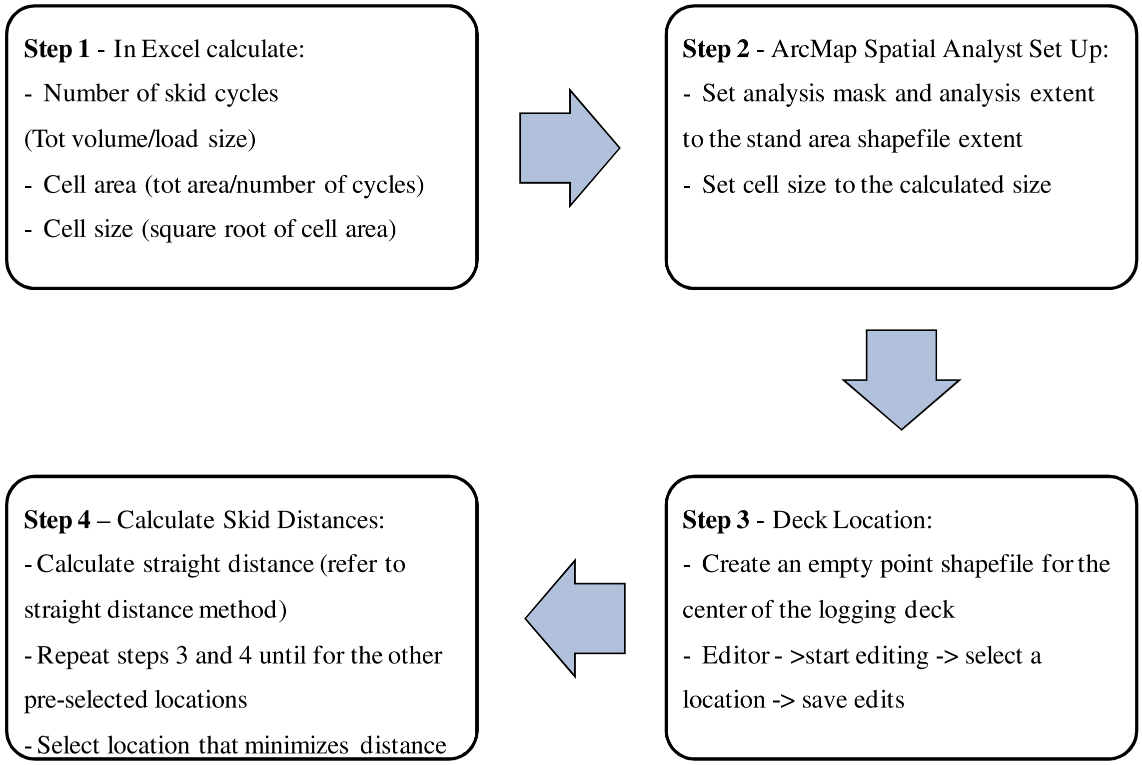

Figure 4.4. — Flow chart of the GIS technique to select logging deck locations as a function of the ratio of total skid travel distances and volume removed.

Table 4.1. – Summary of logging operations and machinery information.

	Stands/	Logging Machines			
Logger	H. Units	Feller Buncher	Loader	Skidder	Load/tonnes
1	2/9	TC[2] 720	Prentice	JD[1] 648GIII (2)	2.651
2	5/9	TC 720	Prentice 384	JD 648GIII (2)[2]	2.651
3	5/6	JD 643J	TC 240B	JD 548GIII	2.039

[1]TC stands for TigerCat and JD stands for John Deere.
[2]Logger 2 did not work full time with 2 skidders, 2nd skidder alternated with another crew.

Table 4.2. – Description of the steps of the technique to estimate total skidding time.

Step	Description	Equation
1	Calculate total number of skidder cycles. Number of skidder cycles equals the number of raster cells	Total harvest volume/skidder load size
2	Calculate raster cell area	Harvest unit area/number of skidder cycles
3	Calculate raster cell size	$(\text{cell area})^{0.5}$
4	Calculate straight distance	Described in the methodology
5	Estimate total skid travel distances by adjusting the straight distances (AStD)	w_{st}*straight distance
6	Calculate total skidder PMH necessary to complete the harvest (totPMH)	AStD/(Dist/PMH)
7	Calculate total skidder SMH necessary to complete the harvest (totSMH)	totPMH/UR
8	Estimation of total number of skidder days necessary to complete the harvest	totSMH/(SMH/day)

Table 4.3. — Summary of the harvesting and skidder productivity data.

Logger	Harvest Unit	Area (ha)	Volume[1] (tonnes)	Skidder PMH	Tonnes/ PMH	Skidder UR (%)
1	1	9.19	1122	38.8	29.0	50
1	2	3.07	200	10.0	20.1	48
1	3	7.84	1086	38.8	28.0	66
1	4	4.64	462	14.3	32.4	38
1	5	19.22	2205	83.8	26.3	76
1	6	11.34	167	8.4	19.9	43
1	7	7.26	1148	42.1	27.3	71
1	8	8.55	603	21.3	28.3	38
1	9	3.19	997	34.0	29.3	70
2	10	23.35	1730	68.3	25.3	34
2	11	12.74	1351	38.0	35.6	54
2	12	10.45	964	15.2	63.3	68
2	13	4.86	526	11.5	45.9	50
2	14	13.99	449	15.3	29.4	45
2	15	10.40	435	17.1	25.4	38
2	16	11.77	600	16.8	35.7	52
2	17	10.51	1669	51.8	32.2	42
2	18	12.86	1152	38.0	30.4	42
3	19	11.79	1589	42.0	37.9	42
3	20	3.83	150	3.6	41.9	36
3	21	6.60	325	8.9	36.5	30
3	22	19.42	1077	31.0	34.8	39
3	23	25.08	2124	89.6	23.7	64
3	24	4.65	573	18.4	31.1	46
			Means			
		10.7	**946**	**31.5**	**32.1**	**53**

[1]Total volume removed from the harvest unit.

Table 4.4. — Skidder travel distances and wander factors.

Harvest Unit	Area (ha)	Distance (Km/harvest)			Wander Factor	
		Actual	Straight	Slope	Straight	Slope
1	9.19	182.0	139.8	147.2	1.30	1.24
2[1]	3.07	51.5	15.0	15.9	3.43	3.24
3	7.84	203.4	158.1	167.3	1.29	1.22
4	4.64	60.6	45.9	48.2	1.32	1.26
5	19.22	343.1	378.4	401.5	0.91	0.85
6	11.34	27.0	21.1	22.1	1.28	1.22
7	7.26	194.3	128.9	135.8	1.51	1.43
8	8.55	102.1	96.9	102.3	1.05	1.00
9	3.19	153.0	72.5	76.8	2.11	1.99
10	23.35	365.7	283.7	300.2	1.29	1.22
11	12.74	167.6	151.2	159.0	1.11	1.05
12	10.45	92.0	127.6	135.2	0.72	0.68
13	4.86	57.6	41.0	43.2	1.40	1.33
14	13.99	72.7	66.6	70.5	1.09	1.03
15	10.40	86.8	53.4	57.0	1.62	1.52
16	11.77	82.7	65.7	69.6	1.26	1.19
17	10.51	253.7	201.0	213.8	1.26	1.19
18	12.86	188.4	136.8	144.3	1.38	1.31
19	11.79	200.7	288.5	315.6	0.70	0.64
20	3.83	28.0	20.1	21.1	1.39	1.32
21	6.60	61.8	72.9	77.1	0.85	0.80
22	19.42	191.5	214.8	226.9	0.89	0.84
23	25.08	476.3	510.5	538.1	0.93	0.89
24	4.65	104.8	78.5	83.3	1.33	1.26
			Means			
		160.7	**145.8**	**154.6**	**1.22**	**1.15**

[1]Excluded outlier (harvest unit 2) from the means.

Table 4.5. ─ Comparisons between actual skidder travel distance (Actual) and the adjusted distances (AStD and ASlD) for straight and slope distances, respectively.

Harvest Unit	Area (ha)	Skidder Travel Distance (km/harvest)			Actual/ AStD	Actual/ ASlD
		Actual	AStD	ASlD		
1	9.19	182.0	170.3	169.5	1.07	1.07
2	3.07	51.5	18.3	18.3	2.81	2.81
3	7.84	203.4	192.5	192.6	1.06	1.06
4	4.64	60.6	55.9	55.5	1.08	1.09
5	19.22	343.1	460.7	462.2	0.74	0.74
6	11.34	27.0	25.6	25.5	1.05	1.06
7	7.26	194.3	156.9	156.3	1.24	1.24
8	8.55	102.1	117.9	117.7	0.87	0.87
9	3.19	153.0	88.3	88.4	1.73	1.73
10	23.35	365.7	345.3	345.6	1.06	1.06
11	12.74	167.6	184.1	183.1	0.91	0.92
12	10.45	92.0	155.3	155.6	0.59	0.59
13	4.86	57.6	49.9	49.8	1.15	1.16
14	13.99	72.7	81.1	81.2	0.90	0.90
15	10.40	86.8	65.0	65.6	1.33	1.32
16	11.77	82.7	80.0	80.1	1.03	1.03
17	10.51	253.7	244.7	246.1	1.04	1.03
18	12.86	188.4	166.6	166.1	1.13	1.13
19	11.79	200.7	351.2	363.3	0.57	0.55
20	3.83	28.0	24.4	24.3	1.15	1.15
21	6.60	61.8	88.8	88.7	0.70	0.70
22	19.42	191.5	261.5	261.2	0.73	0.73
23	25.08	476.3	621.5	619.4	0.77	0.77
24	4.65	104.8	95.6	95.8	1.10	1.09

Table 4.6. — Comparison between actual skidding times (AST) and estimated skidding times (EST).

Harvest Unit	Area (ha)	Volume (tonnes)	Skidding Time (Days) AST	Skidding Time (Days) EST	Difference
1	9.19	1122	4.5	3.3	-27.7%
2	3.07	200	1.5	0.3	-76.7%
3	7.84	1086	4.5	3.7	-18.2%
4	4.64	462	1.8	1.1	-38.9%
5	19.22	2205	8.8	8.8	-0.3%
6	11.34	167	0.9	0.5	-46.5%
7	7.26	1148	4.8	3.0	-36.8%
8	8.55	603	3.0	2.3	-24.9%
9	3.19	997	5.3	1.7	-67.9%
10	23.35	1730	8.0	7.8	-3.0%
11	12.74	1351	5.8	4.1	-29.1%
12	10.45	964	4.7	3.5	-25.2%
13	4.86	526	2.7	1.1	-58.0%
14	13.99	449	2.3	1.8	-21.9%
15	10.40	435	3.0	1.5	-51.3%
16	11.77	600	2.5	1.8	-26.7%
17	10.51	1669	7.5	5.5	-26.2%
18	12.86	1152	5.1	3.7	-26.6%
19	11.79	1589	9.5	7.0	-26.2%
20	3.83	150	1.0	0.5	-51.3%
21	6.60	325	2.5	1.8	-29.1%
22	19.42	1077	7.2	5.2	-27.2%
23	25.08	2124	13.3	12.4	-7.0%
24	4.65	573	4.0	1.9	-52.3%

Table 4.7 – T-test results for the comparison between actual skidding time (AST) and estimated skidding time (EST).

Paired T-test			
Difference	DF	t-value	P-value
AST - EST	22	7.23	<0.0001
Statistics			
N[1]	Mean	Std Dev	Std Error
23	1.2452	0.8256	0.1722

[1]Excluding outlier (harvest unit 2).

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Appendix 1. GPS/GIS Survey

The Global Positioning System (GPS) provides people their location in the form of coordinates (latitude, longitude, and altitude) through the use of a receiver and antenna or GPS unit. The GPS unit collects and stores information that can be referenced as a point (house), line (road), or area (timber stand). GPS units can be purchased for as little as $200.

Mapping software displays data collected from the GPS unit and other sources. Maps provide basic information to help people visual their property and understand management decisions. Mapping software allows quick editing and rapid calculation of distance, slope, and area. Geographic Information Systems (GIS) are mapping systems where the location is linked to data about the timber, soil, and other attributes. The linkage allows for dynamic display and analysis of the area and management decisions.

To learn more about GPS and GIS, refer to the following websites:

http://www.trimble.com/gps/index.shtml

http://www.esri.com/getting_started/new_users/index.html

Survey

The following questions regarding your forest land are very straightforward. Please, complete them as accurately as possible, and where actual information is not available, please use your best guess.

PROPERTY INFORMATION

1. Approximately how many acres of forest land do you own?

O 1 - 9 acres	O 10 – 49 acres
O 50 – 99 acres	O 100 – 499 acres
O 500 – 999 acres	O Over 1000 acres

2. Approximately what percentage of your forest land is covered by:

____ % - Pine ____ % - Hardwood (oak, sweetgum, etc.

3. How important are the following as reasons for ownership of forest land? (check one circle for each item)

	Not Important 1	2	3	4	Very Important 5
Protection of Nature/wildlife	O	O	O	O	O
Land investment	O	O	O	O	O
Income (i.e. timber, hunting lease)	O	O	O	O	O
Enjoy beauty and scenery	O	O	O	O	O
Pass the land to heirs	O	O	O	O	O
Hunting or fishing	O	O	O	O	O
Other	O	O	O	O	O

(please specify)______________________________________

PROPERTY MANAGEMENT INFORMATION

4. What are your plans for your forest land in the next 5 years? (check all that apply)

O Leave as it is
O Commercial harvest (pulpwood or sawtimber)
O Harvest firewood
O Collect non-timber forest products
O Buy more forest land
O Sell some or all forest land
O Convert the forest land to another land use
O Not sure
O Other (please specify)_____________________________

5. Do you have a management plan for your property?

O Yes
O No

6. If the answer to question 5 was "yes", who prepared the plan?

O Yourself O Forestry Consultant
O Industry Forester O State Forester
O Other ______________________________

7. Which management activities have you recently conducted? (check all that apply)

O Planted trees
O Thinning
O Built or maintained roads
O Prescribed burning
O Chemical treatments (herbicides, pesticides, fertilizers)
O Wildlife habitat improvement projects
O None

PERSONAL INFORMATION

8. What is your age?

O Under 30 years O 30 – 40 years
O 41 – 50 years O 51 – 60 years
O 61 – 70 years O Over 70 years

9. What is your current employment status?

O Employed O Self-employed
O Retired O Other ____________________

10. What is your education level?

O Some high school O High school graduate
O Technical degree O Some college
O College graduate O Graduate degree
O Other ______________________________________

COMPUTER SKILLS

11. Rate your computer skills:

O Never used a computer
O Beginner
O Intermediate
O Advanced

12. Do you own a computer?

O Yes O No

13. If the answer to question 12 was "yes", what's the computer used for? (check all that apply)

O Internet/E-mail O Word processing
O Spreadsheets O Financial Information Programs
O Family use O Other _______________________

14. Have you ever attended any computer training course?

O Yes O No

If "yes", please list the most advanced course:
____

15. Rate your use of the internet:

O Never used the internet
O Beginner
O Intermediate
O Advanced

16. Have you ever taken an online training course?

O Yes O No

If "yes", please list the most recent courses:

____

17. Rate your use of e-mail:

O Never used e-mail
O Beginner
O Intermediate
O Advanced

MAPPING INFORMATION

18. Do you have a map of your property?

O Yes O No

19. If the answer to question 18 was "yes", how it was generated?

O By hand (drafting)
O Computer generated
O Not sure

20. Who generated the map?

O Does not apply O Forestry consultant
O Industry forester O State forester
O Yourself O Other _________________________

21. Do you understand GPS technology (Global Positioning System – refer to cover page)?

O Yes
O Some knowledge
O No

22. Do you own a GPS unit? (Do NOT consider the GPS's installed in automobiles)

O Yes O No

If "yes", please specify the make and model ___________________

____

23. Have you used mapping software (GIS – Geographic Information System – refer to cover page)?

O Yes
O No

24. If the answer to question 23 was “yes”, please check the mapping software that you are familiar with. Check all that apply.

O ArcInfo (ESRI)
O MapInfo
O Delorme
O Terrain Navigator
O Fugawi
O Garmin/Magellan
O Microsoft Terra Server
O Google Earth
O Mapquest
O Other____

25. Would you be interested in learning more about GPS or GIS?

O Yes
O No
O Not sure

26. If the answer to question 25 was “yes” how useful for you would be the following ways of learning?

	Not Useful 1	2	3	4	Very Useful 5
Workshops and conferences	O	O	O	O	O
Brochures, books, and pamphlets	O	O	O	O	O
Internet/E-mail	O	O	O	O	O
Video tapes for home viewing	O	O	O	O	O
On-site assistance – Forester	O	O	O	O	O
Other	O	O	O	O	O

(please specify)____

27. How much would you be willing to pay for development of a map or GIS information on your property?

O Less than $200 O $200 to $499
O $500 to $999 O $1000 to $2000
O More than $2000

28. What type of information would you like to receive from Auburn University that would improve your understanding of GPS or GIS?____

____

29. Would you be interested in learning more about the following forestry related topics?

	Not Interested 1	2	3	4	Very Interested 5
Wildlife Management	O	O	O	O	O
Insects/disease	O	O	O	O	O
Invasive Plant Species	O	O	O	O	O
Timber Marketing	O	O	O	O	O
Timber Harvesting	O	O	O	O	O
Best Management Practices	O	O	O	O	O
Hardwood Management	O	O	O	O	O
Timber Prices	O	O	O	O	O
Forest Management	O	O	O	O	O
Forest Economics	O	O	O	O	O

Thank you for taking the time to complete this survey. We really appreciate your collaboration to this study.

Would you like to receive a copy of the results of this survey?

O Yes O No

If yes, how would you like to receive it?

O Mail*

O E-mail**

*Please send a post card to Bruno Folegatti

**Please send an e-mail to: folegbs@auburn.edu

Please, if you have any question, feel free to contact:

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Appendix 2. GPS/GIS Survey Cover Letter

Dear Respondent:

You are invited to participate in a research study entitled, “The Application of Precision Forestry - GPS and GIS technologies,” addressed to forest landowners in Alabama. This study is being conducted by Bruno Folegatti and Dr. Mathew Smidt of the School of Forestry and Wildlife Sciences at Auburn University. Along with this letter is a short questionnaire that asks a variety of questions about you, your forest land, and also about your experience with computers and GPS/GIS.

Considering the vast number of landowners in the state, we are unable to contact all forest landowners. We randomly selected a representative portion of landowners across Alabama that includes you as a potential participant. It should take you about 15 minutes to complete the questionnaire, and your help will be truly appreciated. The results of this study will help us to evaluate and characterize the level of interest of landowners in GPS and GIS technologies. GPS and GIS are powerful technologies that may help landowners improve their practice and financial return. The results will also help us to determine the best approaches to bring information about these technologies to you.

Please be certain that your answers will be strictly confidential, and that any information obtained in this study will remain anonymous. Only statistical results will be published. A “mail-back” envelope is also included in this package, and it is already stamped and addressed to the School of Forestry and Wildlife Sciences. Please **DO NOT** fill the return address space on the “mail-back” envelope. This will assure your anonymity. The “mail-back” envelopes are numbered for the purpose of tracking non-respondents for a second mailing. Tracking will be conducted by a third person in order to secure your anonymity.

Your participation in this study is voluntary, but we do hope you take the time to complete this questionnaire and return it. If you have any questions or concerns about completing this survey or about being in this study, please feel free to contact me at 334-844-8057 or Mathew Smidt at 334-844-1038.

Sincerely,

Bruno Folegatti